

Muon Collider Physics & Detector Studies

Computing Division
Future Projects
Accelerator & Detector Simulations

G P Yeh

1/2011

Intro

- Muon Collider Physics (Eichten, et al)
- A Detector/Group for Lepton Collider
4th Concept
CD/ADS support
Work done up-to-now
- One of the interesting physics areas
- Future



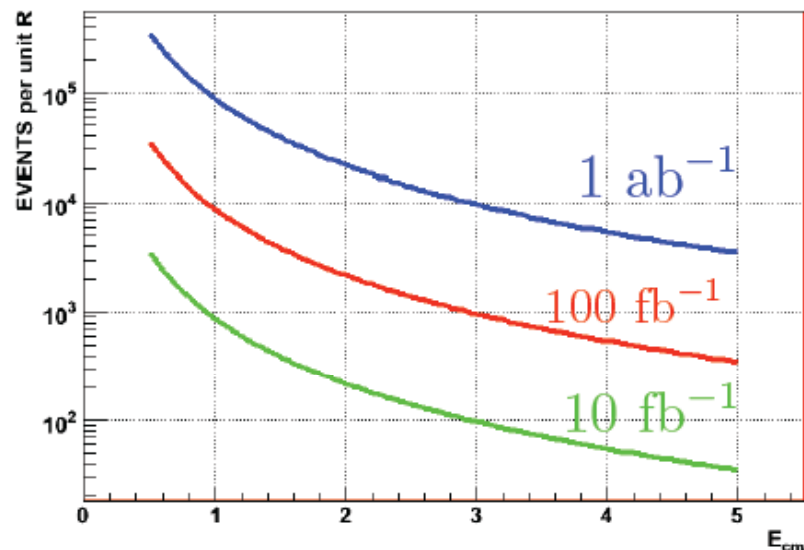
Multi-TeV Muon Collider Basics

□ For $\sqrt{s} > 500 \text{ GeV}$

– Above SM pair production thresholds:

$$R \equiv \sigma / \sigma_{\text{QED}} (\mu^+ \mu^- \rightarrow e^+ e^-) \text{ flat}$$

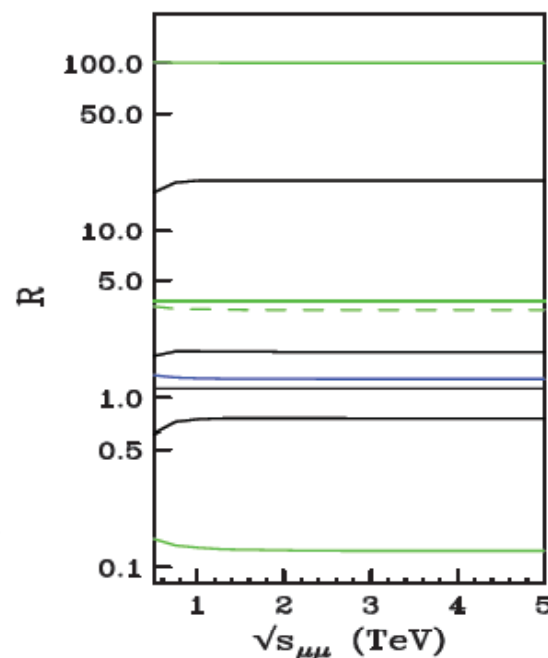
□ Luminosity Requirements



R at $\sqrt{s} = 3 \text{ TeV}$

$O(\alpha_{\text{em}}^2)$ $O(\alpha_s^0)$

$$\begin{aligned} \mu^+ \mu^- (20^\circ \text{ cut}) &= 100 \\ W^+ W^- &= 19.8 \\ \gamma \gamma &= 3.77 \\ Z \gamma &= 3.32 \\ t \bar{t} &= 1.86 \\ b \bar{b} &= 1.28 \\ e^+ e^- &= 1.13 \\ Z Z &= 0.75 \\ Zh(120) &= 0.124 \end{aligned}$$



(one unit of R)

$$\sigma_{\text{QED}}(\mu^+ \mu^- \rightarrow e^+ e^-) = \frac{4\pi\alpha^2}{3s} = \frac{86.8 \text{ fb}}{s(\text{TeV}^2)}$$

For example: $\sqrt{s} = 3.0 \text{ TeV} \Rightarrow 965 \text{ events/unit of R}$

$$\mathcal{L} = 10^{34} \text{ cm}^{-2} \text{sec}^{-1}$$

$$\rightarrow 100 \text{ fb}^{-1} \text{year}^{-1}$$

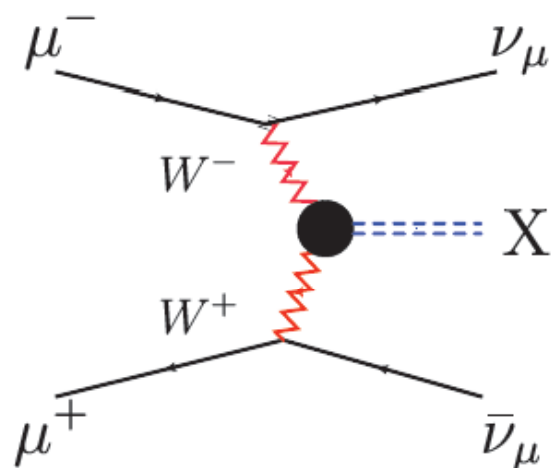
Processes with $R \geq 0.1$ can be studied

Total - 128 K SM events per year



Fusion Processes

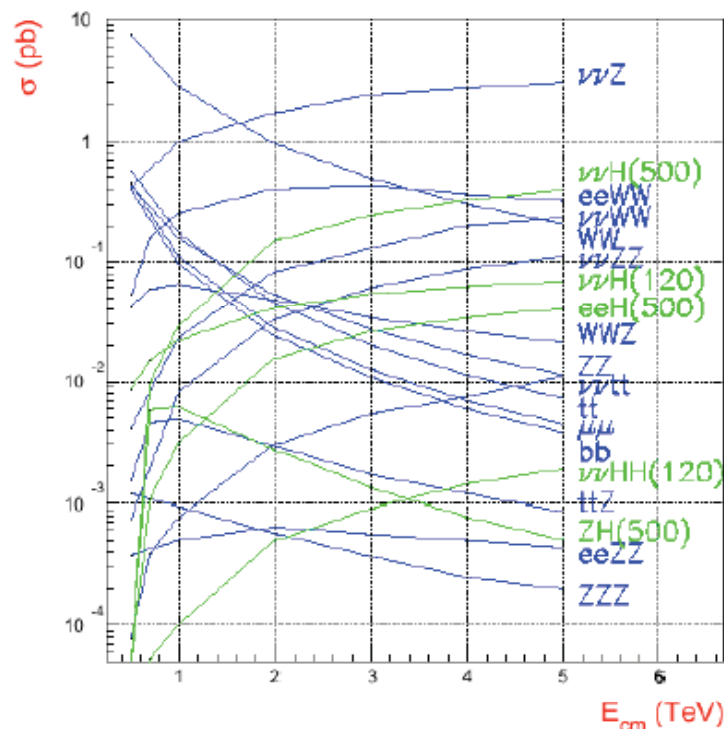
- Large cross sections
- Increase with s .
- Important at multi-Tev energies
- $M_X^2 \ll s$
- Backgrounds for SUSY processes
- t-channel processes sensitive to angular cut



$$\sigma(s) = C \ln\left(\frac{s}{M_X^2}\right) + \dots$$

□ An Electroweak Boson Collider

CLIC (or MC $e \leftrightarrow \mu$)

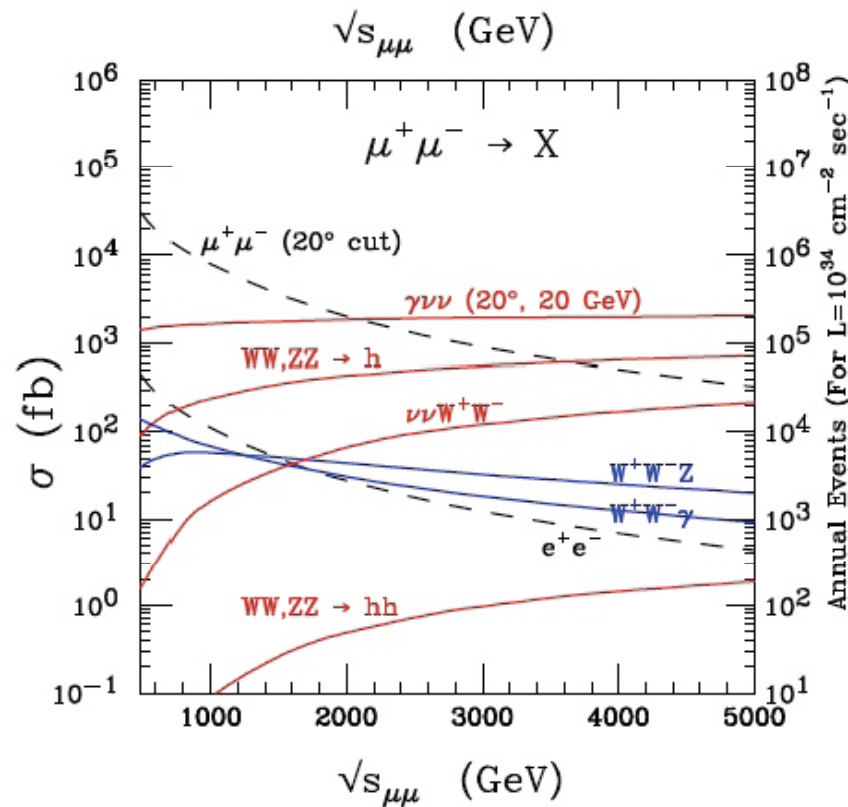


X	R (@ 3 TeV)
Z^0	230
$h^0(500)$	25
W^+W^-	19.8
Z^0Z^0	5.8
$h^0(120)$	5.5
$t\bar{t}$	0.6
$h^0h^0(120)$	0.1



Muon Collider Benchmarks

□ Physics processes similar CLIC/MC for 3TeV energy



Jets from W, Z decays
→ Must resolve W/Z

Many events have large missing energy
→ What is impact for SUSY?

No penalty for heavy flavors
→ Need excellent b and t tagging



Initial Benchmarks

□ Ayres Freitas, Tao Han, E.E.: A first pass at benchmarks

Final states	Exp. considerations	Theo. considerations
$\ell^+\ell^-$, $\ell = e, \mu, \tau$	Ecal, μ -chamber; τ -tagging at HE	Contact interaction
$q\bar{q}$, $q = u, c, s, b$	Hcal, b -tagging at HE	Contact interaction
$\gamma\gamma$	Ecal	QED
$\gamma + \cancel{E}$	Ecal, missing energy	missing mass/dark matter
$W^+W^- \rightarrow q\bar{q}', q\bar{q}'$	Hcal: M_W -reconstruct	New resonances
$W^+W^- \rightarrow \ell\bar{\nu}, q\bar{q}'$	\cancel{E} , M_W -reconstruct	New resonances
$ZZ \rightarrow q\bar{q}, q\bar{q}$	Hcal: M_Z -reconstruct	New resonances
$ZZ \rightarrow \ell^+\ell^-, \nu\bar{\nu}$	Ecal; \cancel{E}	New resonances
$t\bar{t} \rightarrow bW^+ \bar{b}W^+$	E, Hcal, b -tagging, mass reconstruct	New heavy quarks
ZHH	multiple $b\bar{b}$	Higgs self coupling
$W^+W^- \rightarrow HH$	multiple $b\bar{b}$	Higgs self coupling
$\nu\bar{\nu}W^+W^- \rightarrow 4j + \cancel{E}$	Hcal: M_W -reconstruct	WW scattering
$\nu\bar{\nu}ZZ \rightarrow 4j + \cancel{E}$	Hcal: M_Z -reconstruct	WW scattering
$\nu\bar{\nu}t\bar{t}$	Hcal: m_t -reconstruct	$WW \rightarrow t\bar{t}$
$\tilde{\chi}_i\tilde{\chi}_j$	leptons, jets+ \cancel{E}	SUSY
$\tilde{\ell}_i\tilde{\ell}_j$	leptons+ \cancel{E}	SUSY
$\tilde{q}_i\tilde{q}_j$	jets+ \cancel{E}	SUSY

Z'

KK mode

Strong Dynamics

4th Generation,
Little Higgs Models

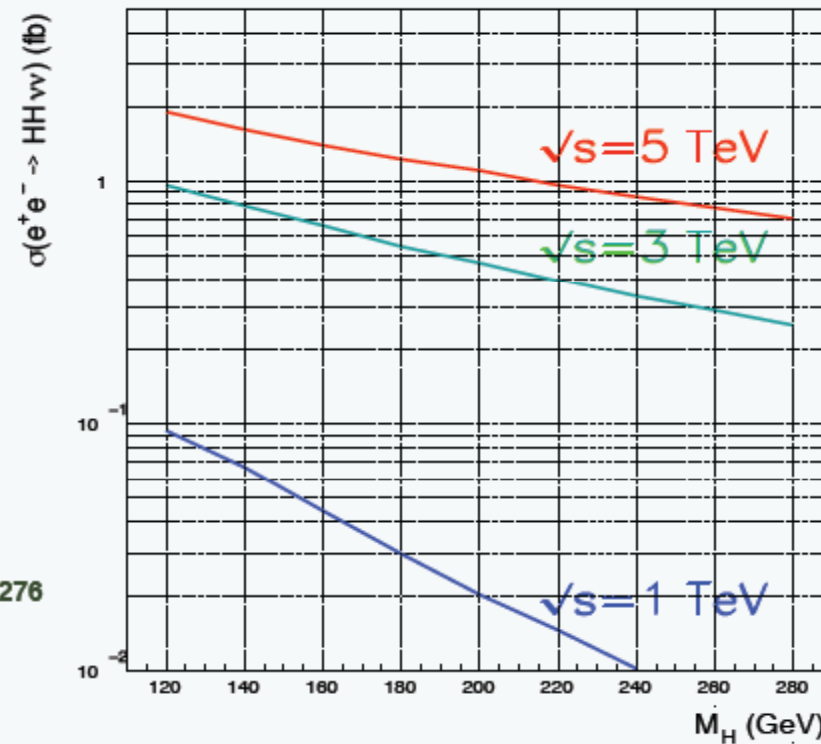
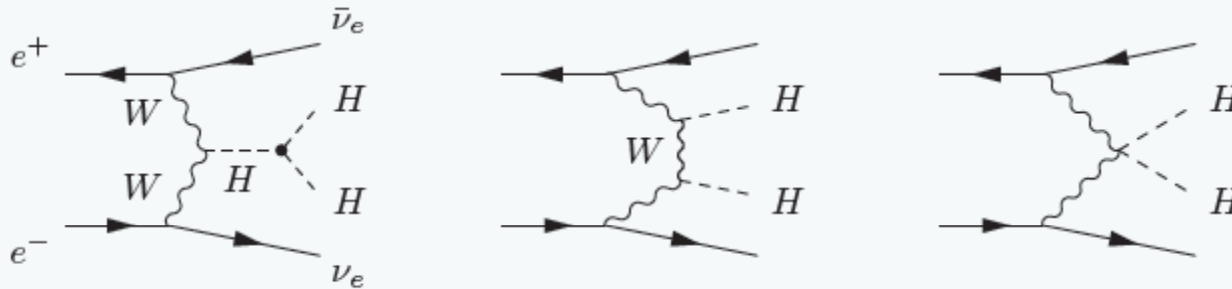
Strong Dynamics

SUSY

Higgs self-coupling

WW double-Higgs fusion: $e^+e^- \rightarrow \bar{\nu}_e \nu_e HH$

CLIC studies



$R \sim s \log s$

Battaglia et al., hep-ph/0111276

H W' Z' SUSY b' t'
Extra Dimensions + ...

MC physics studies that have not been done

J. Lykken

- sLHC/MC complementarity study, analogous to the 2004 LHC/ILC complementarity study
- MC vs CLIC study, with some reasonable ground rules
- “Physics at a 3-4 TeV Muon Collider” (previous comprehensive studies focused on the “FMC”, a ≤ 500 GeV machine)
- Most previous studies of individual channels used the old-fashioned “make some simple cuts” or “make the simplest observable” strategy; need to be re-done using all the information in the events.

Beam Background

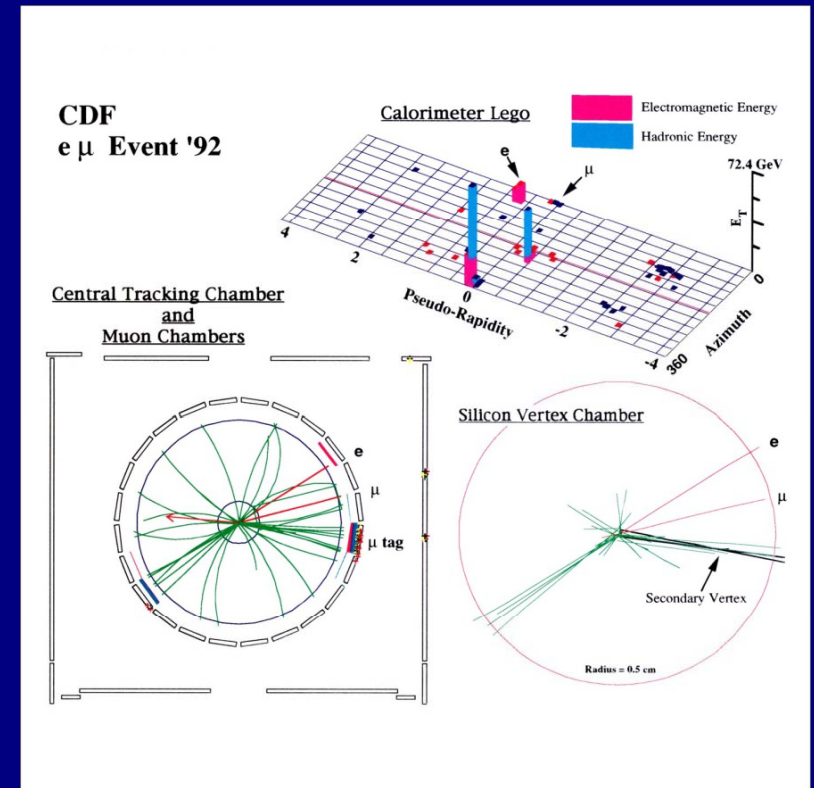
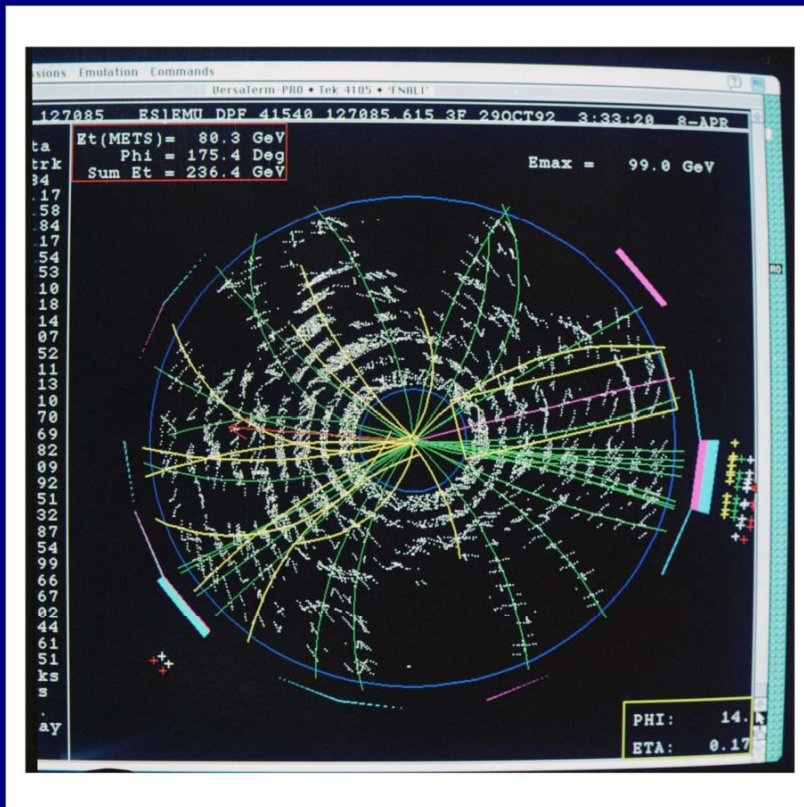
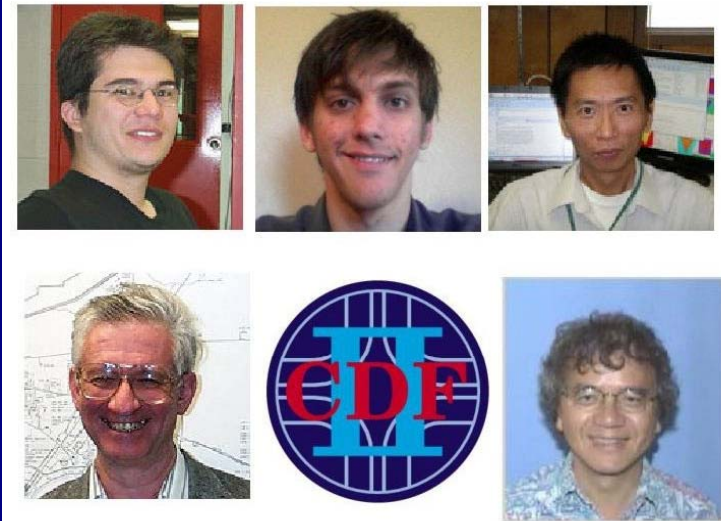
It's the Top

Exclusion of an Exotic Top Quark with $-4/3$ Electric Charge

www.fnal.gov/pub/today/archive_2010/today10-08-12.html

15 years since Discovery

<http://www-cdf.fnal.gov/physics/TopTurnsTen/TTT.html>



International Organizing Committee of the Worldwide Study of Physics and Detectors for Future Linear e+e- Colliders

Co-chairs 1998 - 2003

- Charles Baltay, Yale University
- Sachio Komamiya, University of Tokyo
- David Miller, U. C. London

North American Committee Members

- Robert Carnegie, (Canada)
- Jonathan Bagger, Johns Hopkins University (USA)
- Paul Grannis, SUNY, Stony Brook (USA)
- Steven Olsen, University of Hawaii (USA)
- Charles Prescott, SLAC (USA)

Asian Committee Members

- Shinhong Kim, Tsukuba University (Japan)
- Joo Sang Kang, Korea University Seoul (Korea)
- Takayuki Matsui, KEK (Japan)
- G. P. Yeh, Taiwan
- Tao Huang, University of Beijing (China)

European Committee Members

- Michael Danilov, ITEP (Russia)
- Rolf Heuer, CERN/DESY (Germany)
- Marcello Piccolo, Frascati (Italy)
- Francois Richard, Orsay (France)
- Ron Settles, Munich (Germany)

2 of my concerns
Calorimeter
Software



Fermi National Accelerator Laboratory

FERMILAB-Conf-99/260

Top Quark Mass Measurement from $t\bar{t}$ DiLepton Events at Linear Collider

J. Antos

*IEP Slovak Academy of Sciences
Slovakia and Academia Sinica, Taiwan*

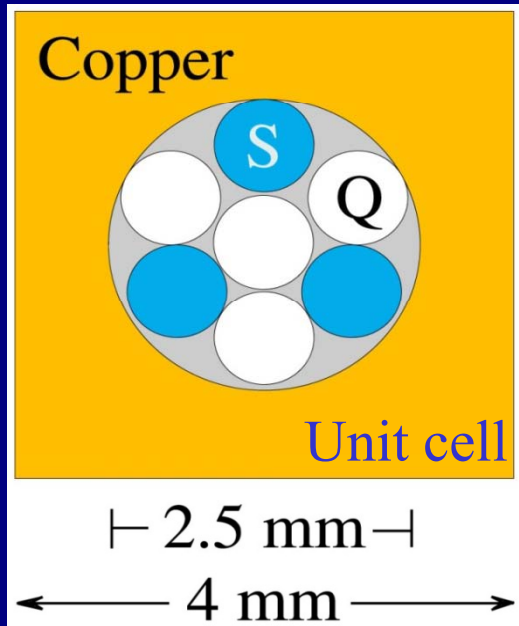
G.P. Yeh

*Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510*

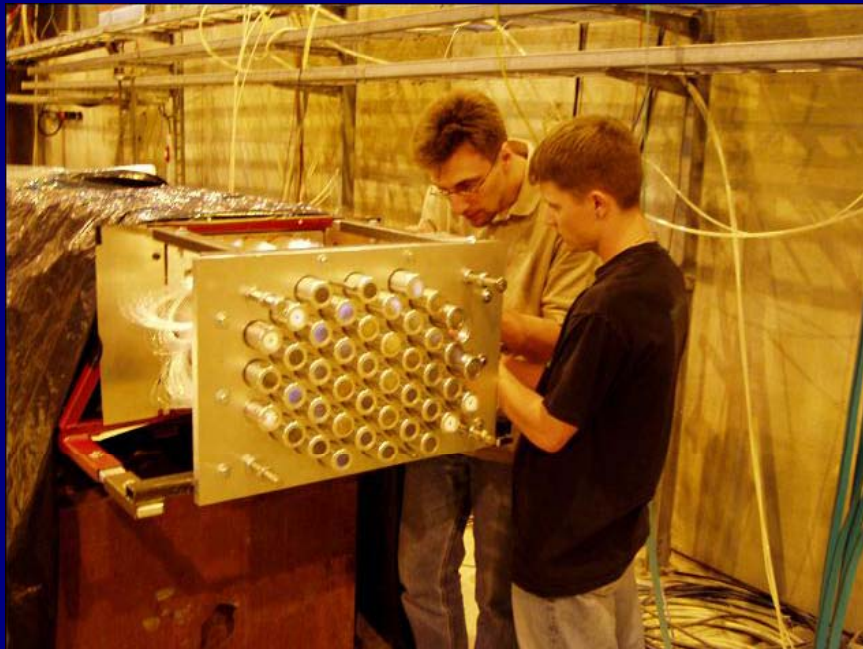
Precision Top measurements @ future Lepton Collider

Dual Readout fiber calorimeter

first developed by R. Wigmans



Back end of
2-meter deep
module



Physical
channel
structure



<http://www.phys.ttu.edu/dream>

The 4th Concept Collaboration

Fourth ("4th") Detector Collaboration

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D. Denisov, I. Fang, L. Garren, S.R. Hahn, A. Hocker, C. Milstene, M. Mishina, S. Mishra,
D. Pushka, V. Scarpine, R. Stefanski, Z.J. Tang, S. Timm, R. Wands, H. Wenzel,
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Iowa State University, Ames, IA 50011 USA

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Department of Physics, Texas Tech University Lubbock, TX 79409-1051 USA

140 collaborators, 33 institutions, 15 countries

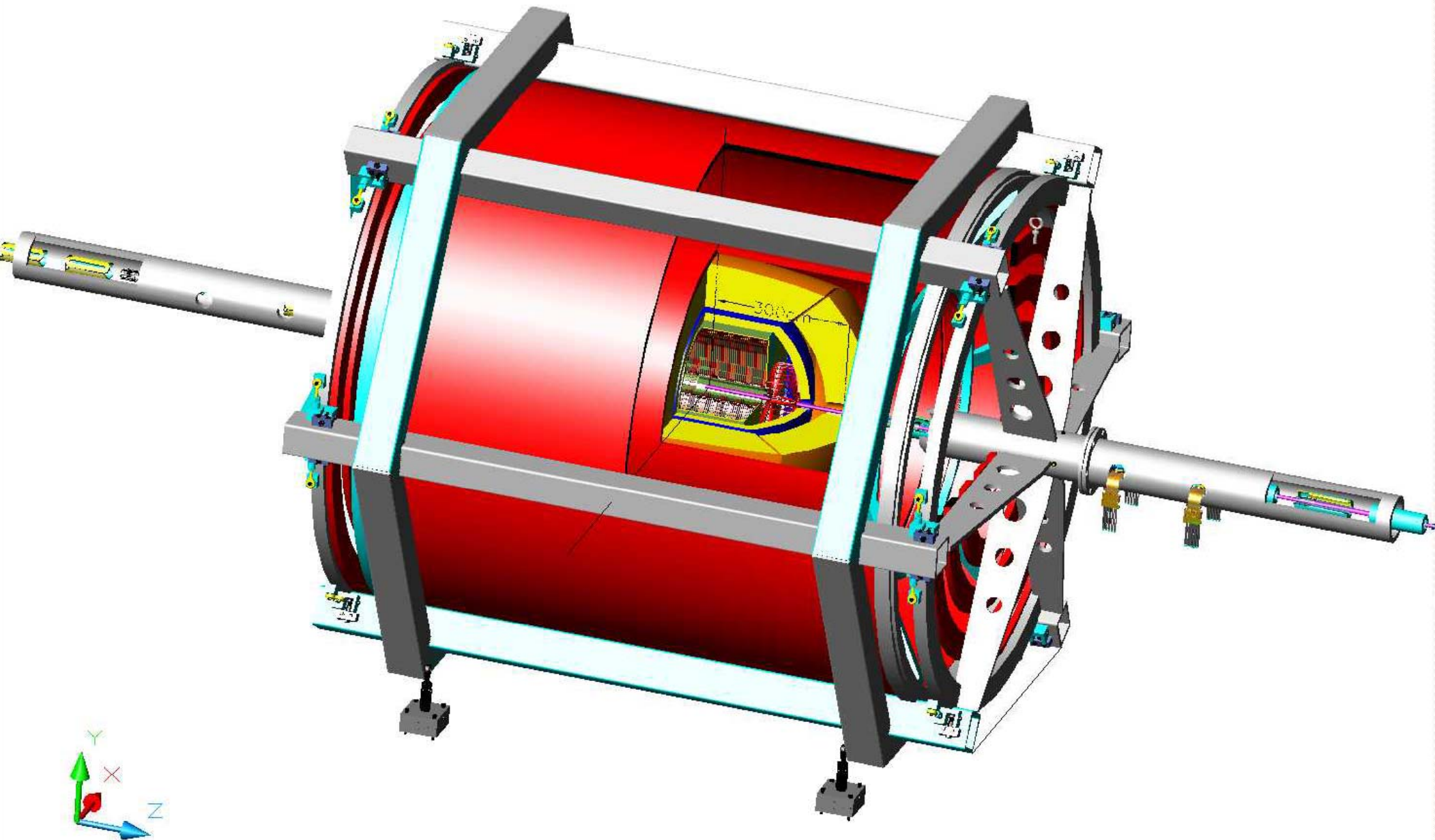
31 March 2009

Started @ Snowmass
8 / 2005

140 Members
33 Institutions
15 Countries

www.4thconcept.org

4th Concept Detector



ILD group

- Representatives: Ties Behnke (DESY), Yasuhiro Sugimoto (KEK)
- Participating Institutions: 169 (28 countries)

SiD group

- Representatives: John Jaros (SLAC), Harry Weerts (ANL)
- Participating Institutions: 49 (8 countries)

4th concept group

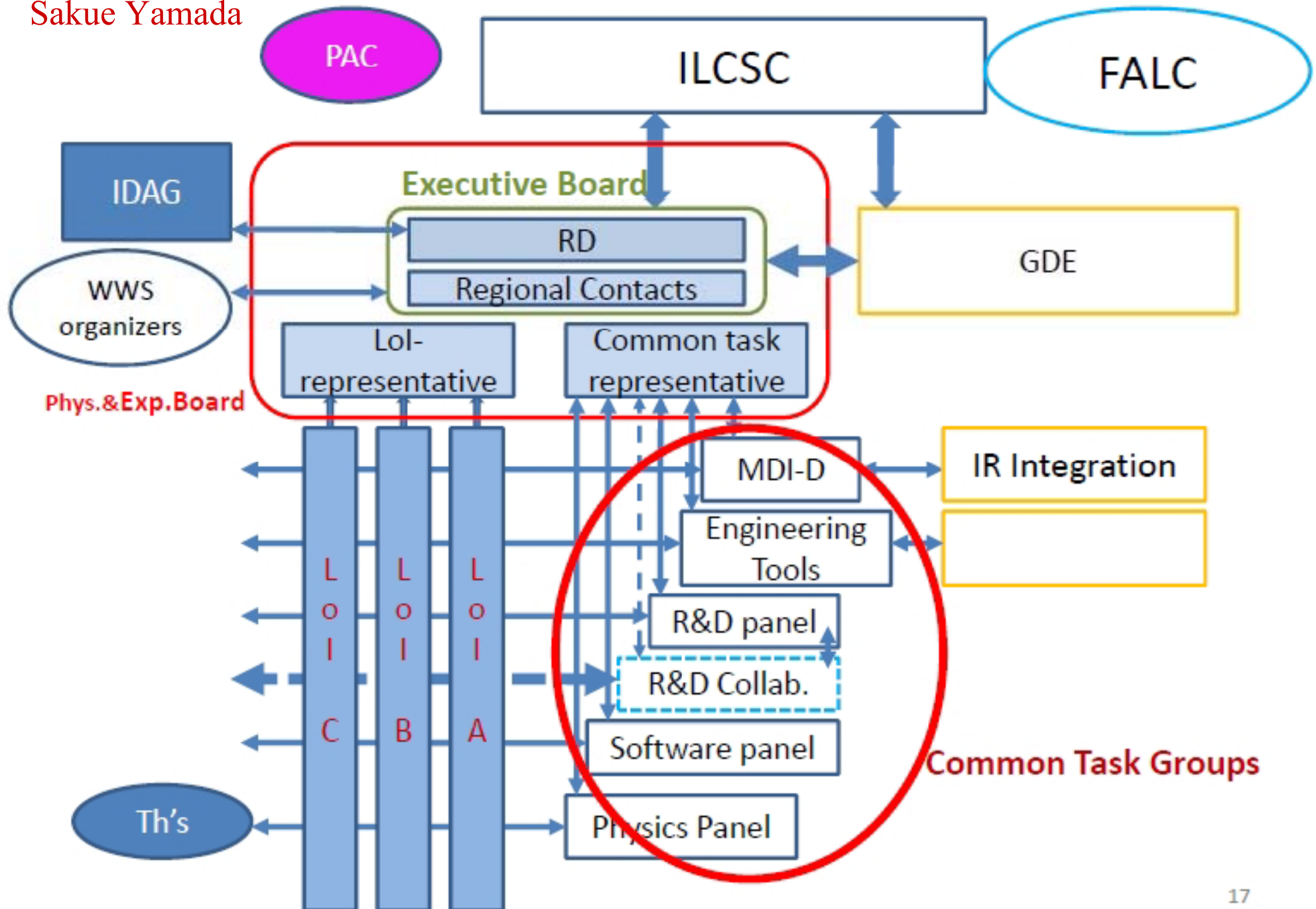
- Representatives: John Hauptman (Iowa State), G.P. Yeh (FNAL)
- Participating Institutions: 17 (10 countries)

Communication channel with the LOI groups

LOI Representatives and the Directorate meet regularly,
once per month

Oct, 2008

Sakue Yamada



4th Concept Detector

Many presentations at LCWS Workshops 2006 - 2009

http://www-cdf.fnal.gov/~gpyeh/4th_SiLC.pdf

http://www.silc.to.infn.it/doc/papers/gp_yeh.pdf

Torino, Dec. 17-19, 2007
SiLC Collaboration Meeting

http://www-cdf.fnal.gov/~gpyeh/4th_Sendai.pdf

Sendai, Mar. 3-6, 2008
TILC

Letter of Intent from the
Fourth Detector (“4th”) Collaboration at the
International Linear Collider

<http://www.4thconcept.org/4LoI.pdf>

Mar. 31, 2009

<http://www.4thconcept.org/4IDAG.pdf>

4th Concept Detector Collaboration Meeting

Future work for

ILC

Muon Collider

CLIC

GP Yeh

9/25/2009

http://www-cdf.fnal.gov/~gpyeh/Collaboration_Meeting.ppt

Muon Collider Physics Workshop 2009

Fermilab, Nov. 10-12

- Detector Design Strategies John Hauptman
- 50-T solenoid John Hauptman
- Simulation and Performance of Detectors Corrado Gatto
- Near zero mass cluster-timing Drift Chamber Francesco Grancagnolo
- ILCroot: Infrastructure for Large Collider based on root Corrado Gatto
- W-Z Reconstruction Anna Mazzacane
- Calorimetry John Hauptman
- Calorimetry Vito Di Benedetto

Calorimetry

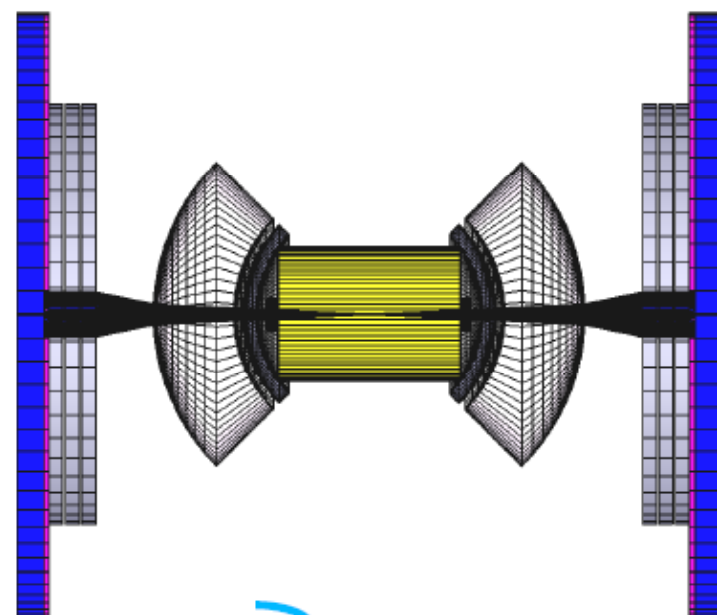
Hans Wenzel

Tools for Calculations and Simulations

Stephen Mrenna

"The 4th Concept" Detector

@ μ Collider



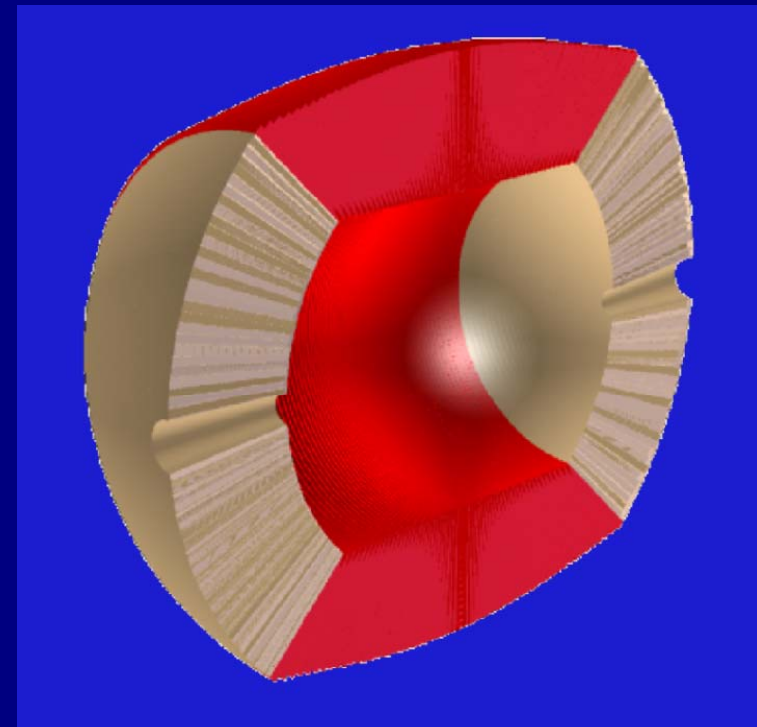
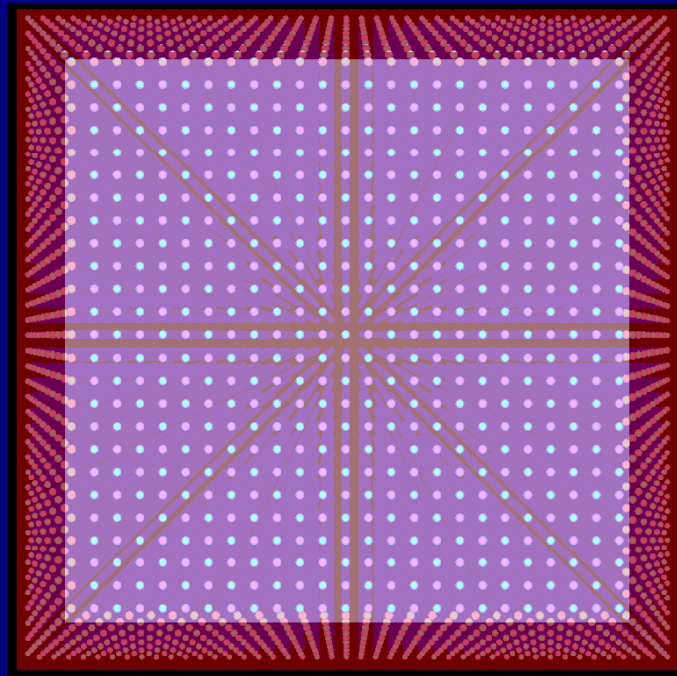
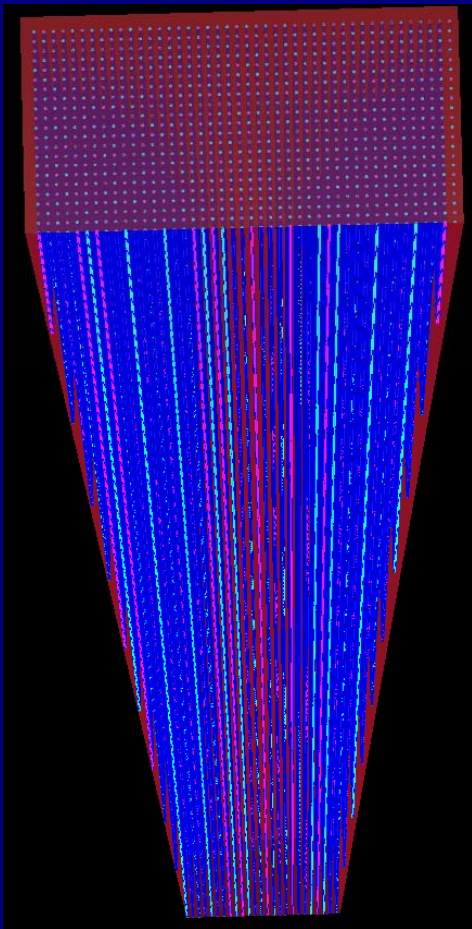
Replace
the DCH

- VXD (SiD Vertex)
- Silicon Pixel Tracker (SIPT)
- Forward Tracker Disks (preliminary version) (FTD)
- **ECAL (BGO Dual Readout)**
- **HCAL (Fiber Multiple Readout)**
- MUDET (Dual Solenoid, Iron Free, Drift Tubes)
- Inner Tungsten nose + Borate Polyethylen and Tungsten walls

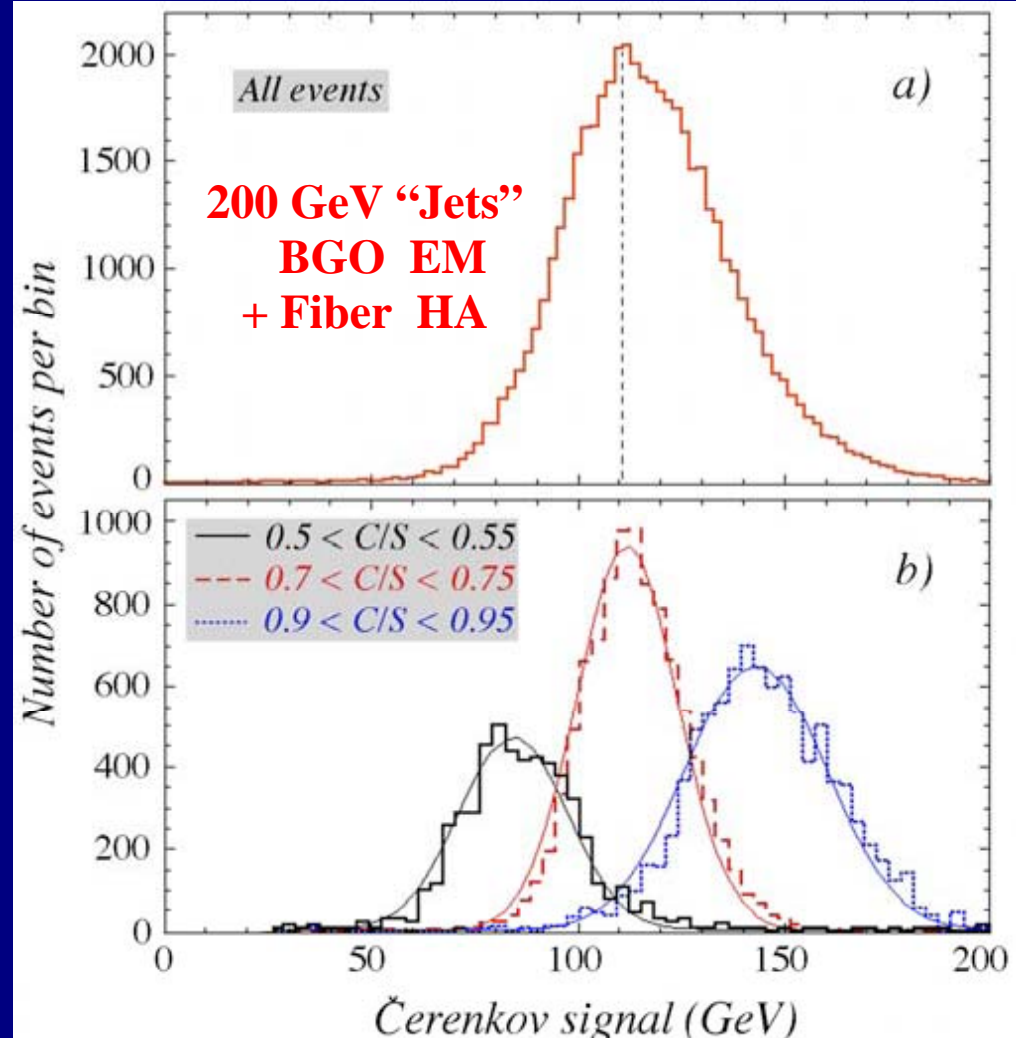
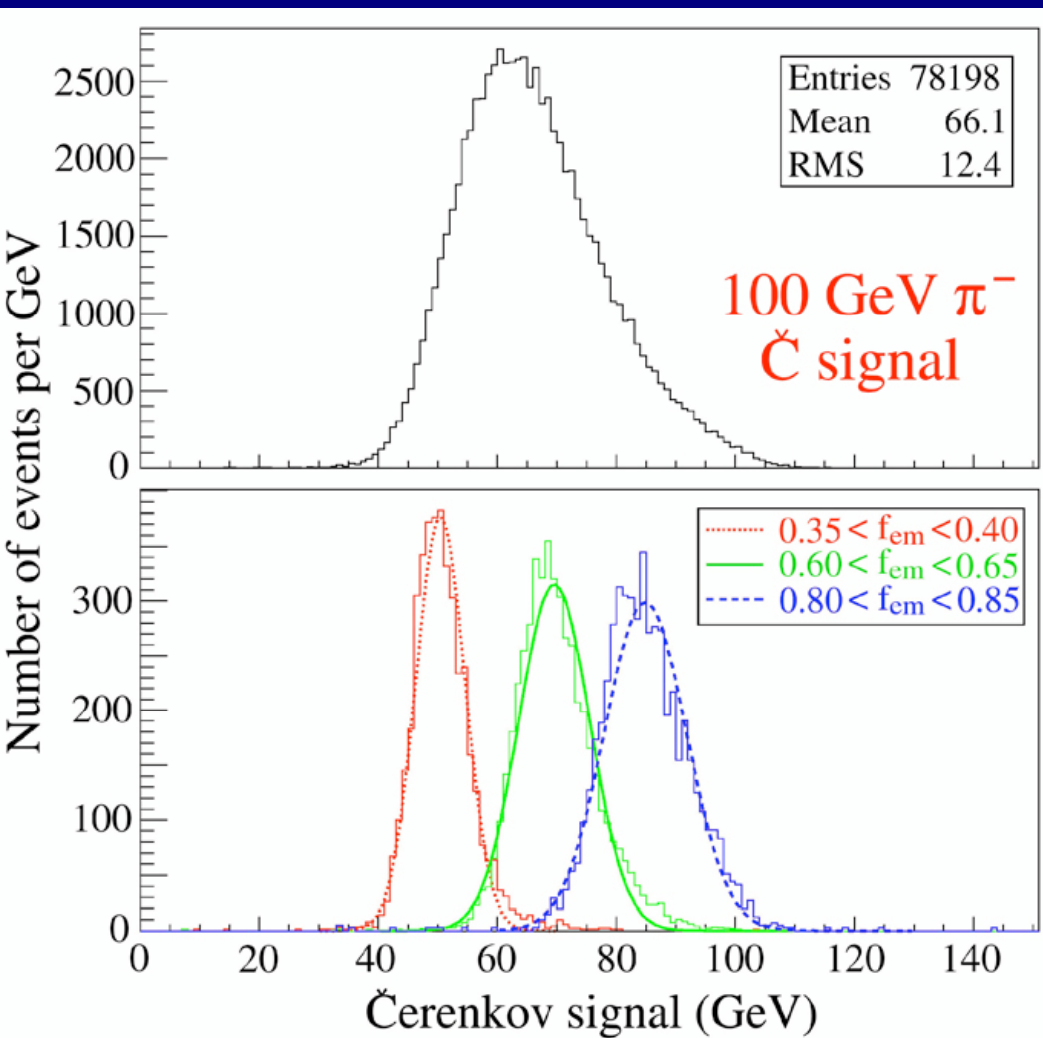
Dual Readout calorimeter



DREAM calorimeter



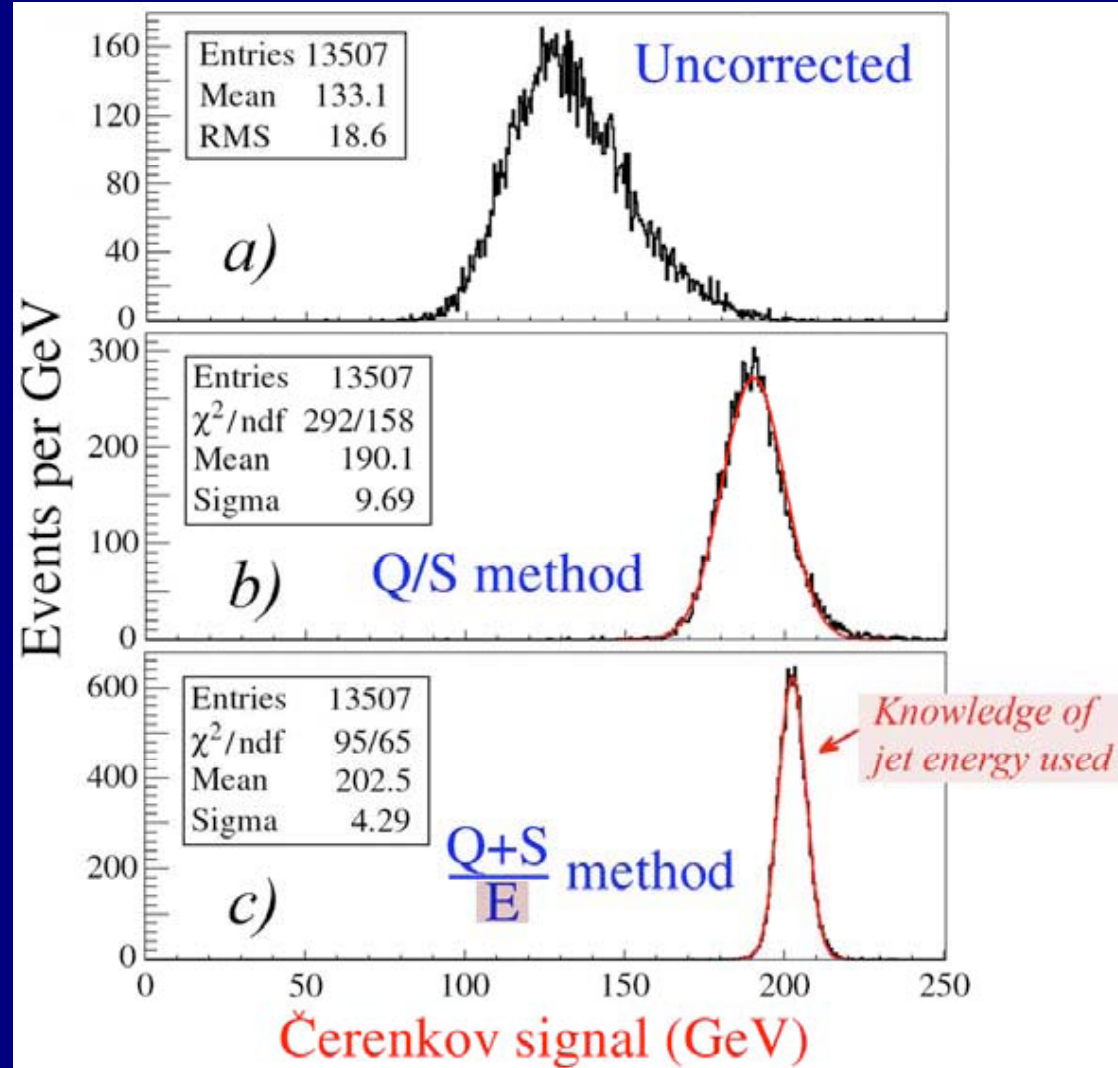
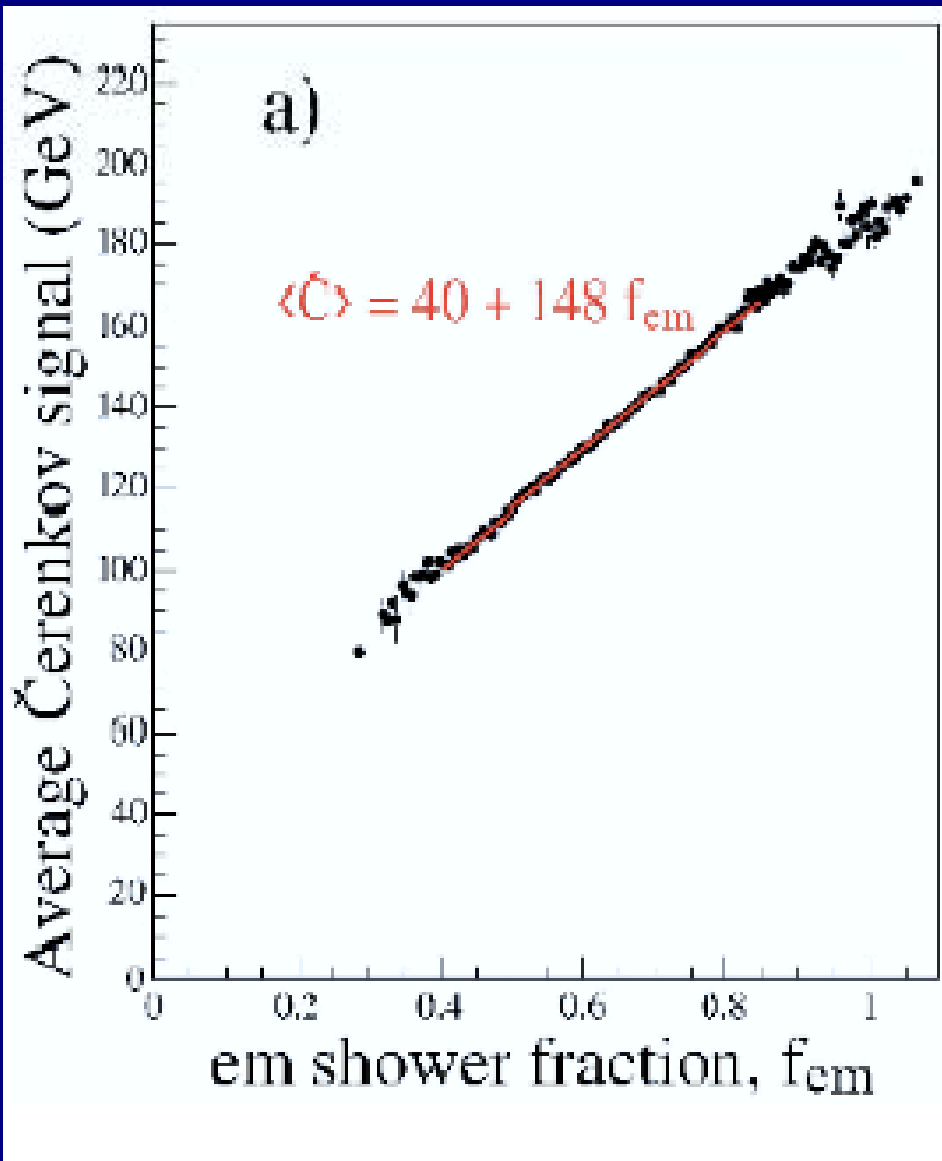
Hadron Energy Resolution & fluctuation of EM fraction in hadron showers



DREAM Calorimeter Test Beam Data

NIM A610 (2009) 488.

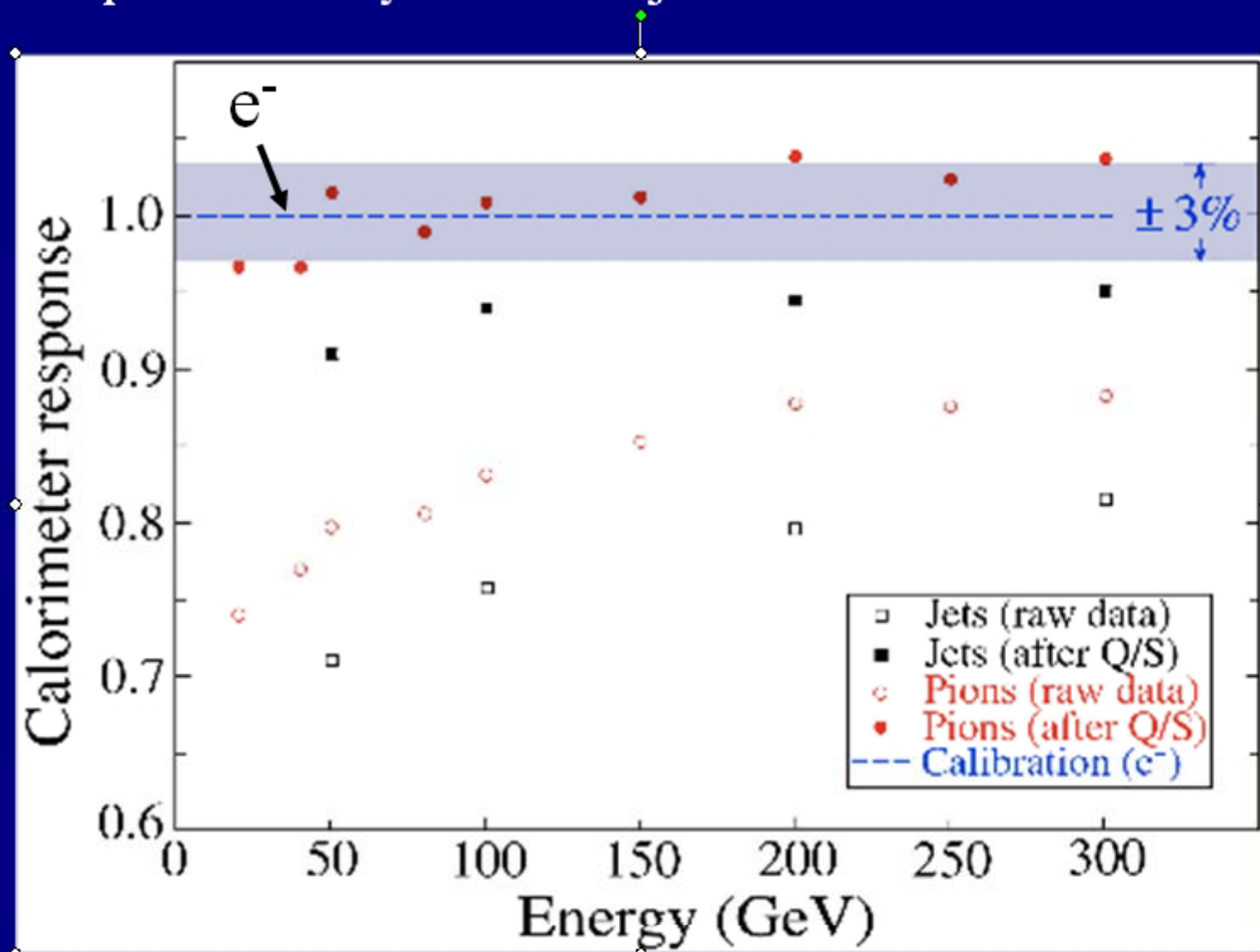
DREAM data 200 GeV π^- Energy response



Data NIM A537 (2005) 537.

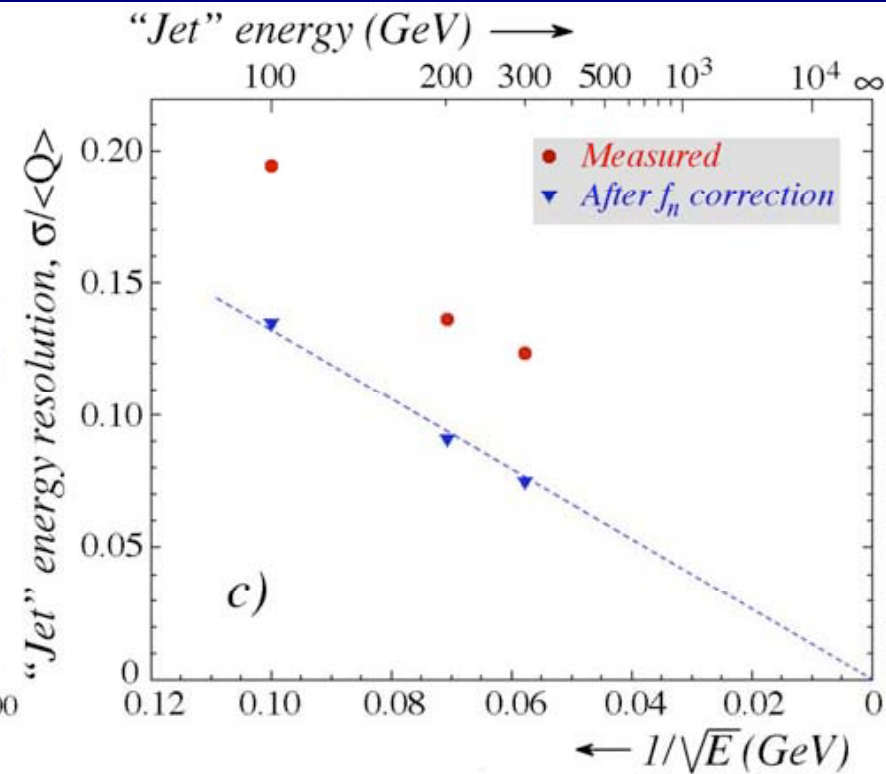
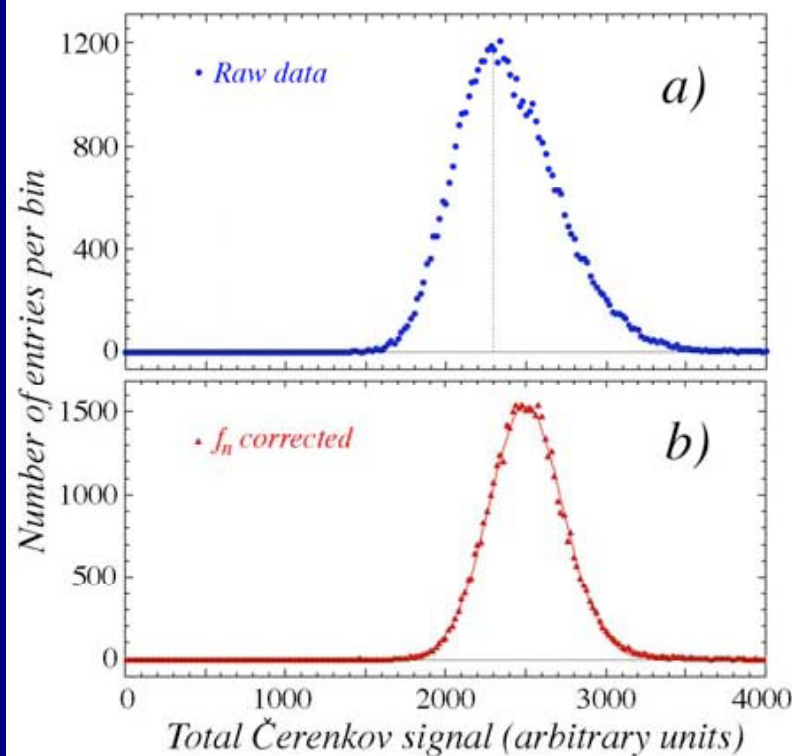
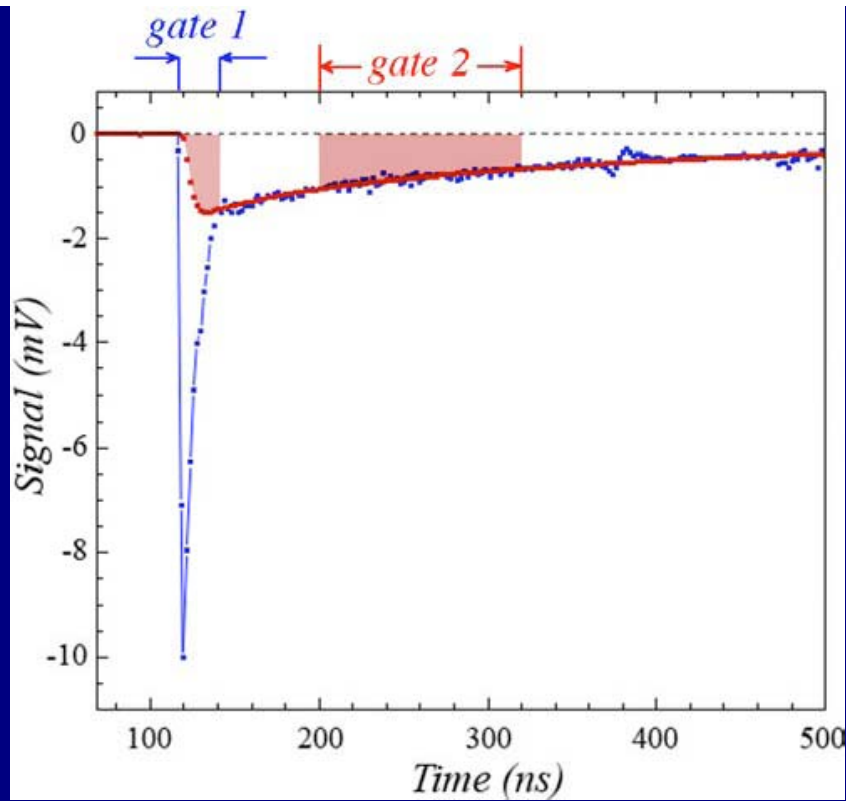
More important than good Gaussian response:

DREAM module calibrated with 40 GeV e^-
responds linearly to π^- and “jets” from 20 to 300 GeV.



DREAM Calorimeter Test Beam Data

C, S Time measurement
→ Energy Correction
for Neutron Fraction



Publications in dual-readout calorimetry

1. "Muon Detection with a Dual-Readout Calorimeter" NIM A533 (2004) 305-321.
2. "Hadron and Jet Detection with a Dual-Readout Calorimeter" NIM A537 (2005) 537-561.
3. "Electron Detection with a Dual-Readout Calorimeter" NIM A536 (2005) 29-51.
4. "Comparison of High-Energy Electromagnetic Shower Profiles Measured with Scintillation and Cerenkov Light" NIM A548 (2005) 336-354.
5. "Separation of Scintillation and Cerenkov Light in an Optical Calorimeter" NIM A550 (2005) 185-200.
6. "The DREAM Project - Results and Plans" NIM A572 (2007) 215-217.
7. "Contribution of Cerenkov Light to the Signals from Lead Tungstate Crystals" NIM A582 (2007) 474-483.
8. "Measurement of the Contributions of Neutrons to Hadron Calorimeter Signals" NIM A581 (2007) 643-650.
9. "Dual-Readout Calorimetry with Lead Tungstate Crystals" NIM A584 (2007) 273-284.
10. "Comparison of High-Energy Hadronic Shower Profiles Measured with Scintillation and Cerenkov Light" NIM A584 (2007) 304-318.
11. "Effects of Temperature Dependence of the Signals from Lead Tungstate Crystals" NIM A593 (2008) 530-538.
12. "Separation of Crystal Signals into Scintillation and Cerenkov Components" NIM A595 (2008) 359-374.
13. "Neutron Signals for Dual-Readout Calorimetry" NIM A598 (2009) 422-431.
14. "Dual-Readout Calorimetry with Crystal Calorimeters" NIM A598 (2009) 710-721.
15. "New Crystals for Dual-Readout Calorimetry" NIM accepted
16. "Quartz Fibers and the Prospects for Hadron Calorimetry at the 1% Resolution Level" Tucson CALOR (1997) 182

Dual-Readout Calorimetry with a Full-Size BGO Electromagnetic Section

DREAM

17th

NIM publication

N. Akchurin^a, F. Bedeschi^b, A. Cardini^c, R. Carosi^b, G. Ciapetti^d,
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J. Hauptman^g, M. Incagli^b, F. Lacava^d, L. La Rotonda^h,
T. Libeiro^a, M. Livan^f, E. Meoni^h, D. Pinci^d, A. Policicchio^{h, 1},
S. Popescu^a, F. Scuri^b, A. Sill^a, W. Vandelliⁱ,
T. Venturelli^h, C. Voena^d, I. Volobouev^a and R. Wigmans^{a, 2}

*Nucl. Instrs.
Meths.*

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Italy

^e INFN Sezione di Pavia, Italy

^f INFN Sezione di Pavia and Dipartimento di Fisica Nucleare e Teorica, Università di
Pavia, Italy

^g Iowa State University, Ames (IA), USA

^h Dipartimento di Fisica, Università della Calabria and INFN Cosenza, Italy

ⁱ CERN, Genève, Switzerland

Abstract

Beam tests of a hybrid dual-readout calorimeter are described. The electromagnetic section of this instrument consists of 100 BGO crystals and the hadronic section is made of copper in which two types of optical fibers are embedded. The electromagnetic fraction of hadronic showers developing in this calorimeter system is determined event by event from the relative amounts of Čerenkov light and scintillation light produced in the shower development. The benefits and limitations of this detector system for the detection of showers induced by single hadrons and by multiparticle jets are investigated. Effects of side leakage on the detector performance are also studied.

PACS: 29.40.Ka, 29.40.Mc, 29.40.Vj

Key words: Calorimetry, Čerenkov light, crystals, optical fibers

1 Introduction DREAM Dual Readout Calorimeter

DREAM¹, based on an idea proposed in 1997 [1], started in 2002 as a generic detector R&D project, intended to explore (and, if possible, eliminate) the obstacles that prevent calorimetric detection of hadrons and jets with a comparable level of precision as we have grown accustomed to for electrons and photons. The initial collaboration, consisting of fewer than 10 physicists, built a prototype detector (the Dual-Readout Module) at Texas Tech University, which was shipped to CERN and successfully tested at the SPS in 2003 and 2004. The excellent results obtained in these tests generated a lot of interest, and the collaboration has considerably expanded since that time.

In these early tests, we concentrated on the dominating source of fluctuations, *i.e.* fluctuations in the electromagnetic content of hadron showers. After these initial studies, in which the effects of these fluctuations on hadronic calorimeter performance were successfully eliminated, the collaboration has focused on the remaining effects, which rose to prominence as a result: Sampling fluctuations, signal quantum statistics and nuclear breakup effects.

In this context, we have also carried out (in 2006-2009) a series of successful studies of crystal calorimeters, and of methods to split the signals from these crystals into scintillation and Čerenkov components. Recently, a full-size crystal matrix consisting of 100 BGO crystals served as the em section of a hybrid calorimeter system, in which the original fiber calorimeter formed the hadronic section.

The results of these, and many other studies of all aspects of the limitations of hadronic calorimeter performance that have been carried out by the DREAM collaboration from 2003-2009 are described in 17 papers in the refereed literature. These are listed in Section 3.6.

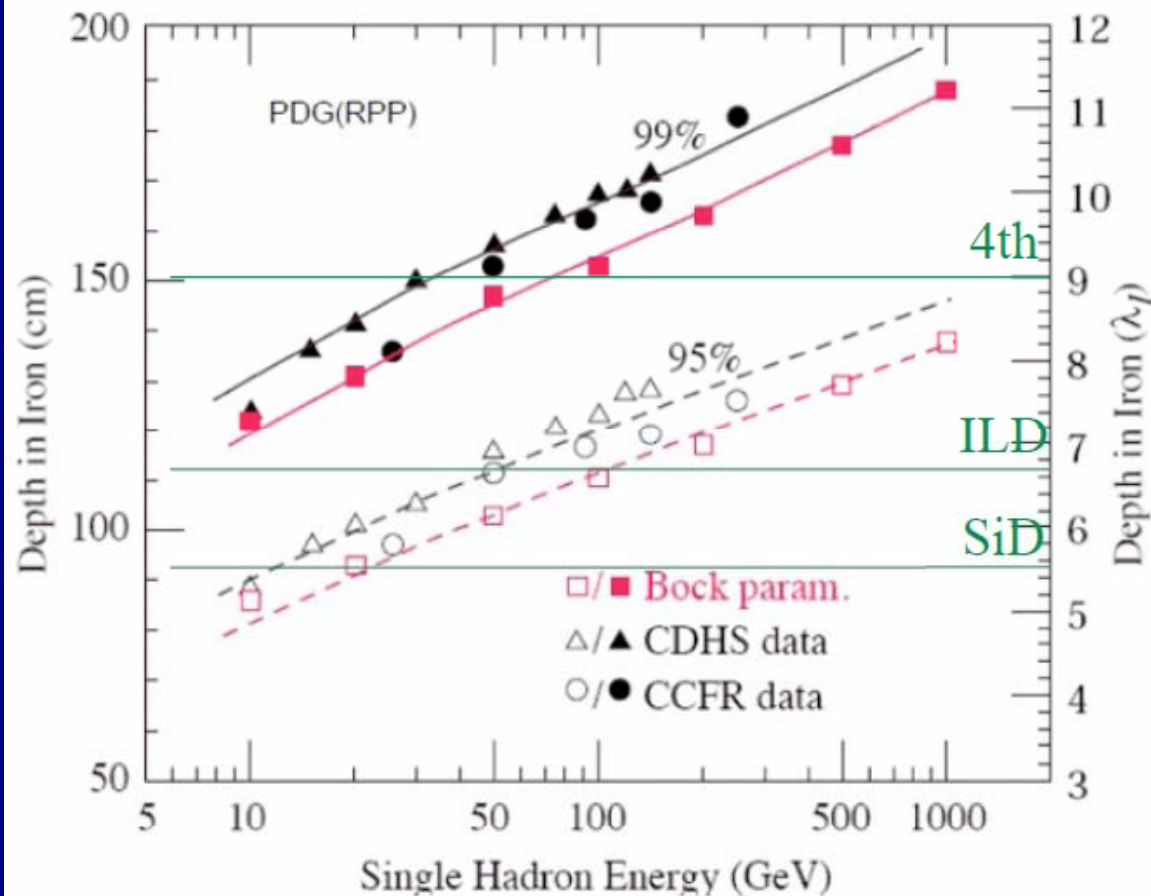
Even though DREAM has always been in essence a generic R&D project, several collaboration members have of course practical applications in mind. These applications include a detector for an experiment at a future Linear e^+e^- Collider in the TeV energy range (ILC, CLIC) [2], and an upgrade of existing calorimeter systems, *e.g.* in the context of SLHC.

The DREAM project has been carried out in a phased manner. That also applied to the funding. At each stage, we have set new goals, based on what was learned during the previous stage. In the period 2002 - 2009, funding for the different stages of this project was received from the US department of Energy (through the ADR program), the State of Texas (ARP program), Texas Tech University and INFN (Gruppo V).

We have now reached the point where we believe that we have all the ingredients in hand to build the perfect calorimeter system, or at least a calorimeter system that meets and exceeds the performance requirements of experiments at the ILC and CLIC. We have proposed to prove this statement by building and testing such a detector to our funding agencies, which have responded favorably. We have received \$540K in FY09/10 funds from the US Department of Energy, and the Italian Ministry of Industry and University Research has allocated €370K. Substantial support from INFN comes in the form of workshop time, crucial for the construction of the detectors. Work on the construction of this new detector has started.

+ \$150k
DOE to
Iowa State

How many interaction length for HCAL?



ILD	SiD	4th
5.7λ	4.5λ	8.0λ
ECAL $\sim 1 \lambda$		1.3λ

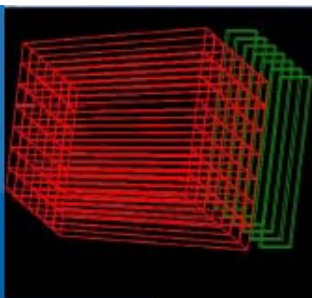
	W	U	Fe
density [g/cm ³]	19.3	19.0	7.9
λ_{Int} [cm]	10.0	11.0	16.8
X_0 [cm]	0.3	0.3	1.8

Expl: to absorb 95% of the energy of a 300 GeV pion $\rightarrow 8 \lambda_I$

April 2009

TILC09 workshop
Dieter Schlatter (CERN)

14



Another R & D

Crystal Calorimetry

Fermilab 

Adam Para, Steve Magill,
GiovanniPauletta, Hans Wenzel
Krzysztof Genser, Anna Driutti,
Nayeli A Rodriguez- Briones,
Jeffrey Hill, Paul Rubinov, Eric Shinn,
Diego Cauz....

- A totally active dual read out calorimeter has been implemented within the SID software framework.

Algorithms have been developed to detect and correct for leakage.

- Algorithms have been developed to correct for magnetic field affecting invariant mass reconstruction.

PFA is being adapted to work with this calorimeter.

- Geant 4 is a good tool to model optical processes, but will work with Geant 4 team to improve hadronic physics models.

Need to study physics scenarios demonstrating the need for such a

- calorimeter.

We are getting ready to put crystals and test beam modules into the test

- beam here at Fermilab.

R&D necessary to find the right crystal (dense, affordable, UV-

- transparent, Scintillation and Cerenkov spectrum well separated, slow scintillation time const....)

R&D necessary to find the right sensor (SiPMT's ?)

-

Matrix Element Calculators

Automatically calculate code needed for a given HEP **partonic** process and generate events

- AlpGen@ <http://m.home.cern.ch/m/mlm/www/alpGen/>
- CompHep@ <http://theory.sinp.msu.ru/comphep>
- Grace@ <http://atlas.kek.jp/physics/nlo-wg/grappa.html>
- MadEvent@ <http://madgraph.hep.uiuc.edu/index.html>
- Sherpa/Amegic++@ <http://141.30.17.181/>²
- WHIZARD@ <http://whizard.event-generator.org/>

Advantages and disadvantages of each

These supplement the event generators

²ME+PS



Computing Resources

- Computing Division: Accelerator Modeling and R&D (AMR)
<http://cd-amr.fnal.gov/> P. Spentzouris et al
- Introduction to ILCSIM
Lynn Garren, Fermilab
Nov. 8, 2007
<http://ilcdoc.linearcollider.org/record/12298/files/ILCresources.pdf>
<http://cd-amr.fnal.gov/ilc/ilcsim/ilcsim.shtml> M. Fischler et al
- FermiGrid
Steve Timm, Keith Chadwick
<http://fermigrid.fnal.gov/>
- Open Science Grid
<http://www.opensciencegrid.org/>

Fermilab CD

Lecce

Project Information

In the area of Project Information, this document should answer these questions:

- a) How many students, and for what periods, are supposed to be here doing these activities, and how solid is that number.

The original memo mentions multiple students but when it comes down to supplying funds, we will need something more concrete.

Mark Fischler

Amber Boehnlein

Bob Tschirhart

We have a planning table of our project with tentative names and dates. A detailed plan of the project should involve all of the parties interested: G.P. (on behalf of FNAL CD), Marcel, and Corrado. There is an interest from the groups of Paris VI and Valencia involved in SiLC detector on the simulation of the Forward Tracker and some work is already going on with them. Their ideas are welcome. Therefore, the present document is intended mostly as a starting point, with possible evolution during the course of the project.

	Jun	Jul	Aug	Sept	Oct	Nov
Si Tracker and Forward tracker Geometry						
Si Tracker, DCH and Forward tracker Fasterecpoints						
Strips Digitization						
Drift Chamber Digitization						
Reconstruction in Central + Forward Tracker						
Calorimetry						
Jet reconstruction						
Vertex Studies						

Daniele Barbareschi

Gianfranco Tassielli

Anna Mazzacane

Vito Di Benedetto

Fedor Ignatov

As indicated, it requires 5 months coverage for Daniele (with Marcel's funds) and 8 months for the rest of the people.

Fermilab CD

Lecce

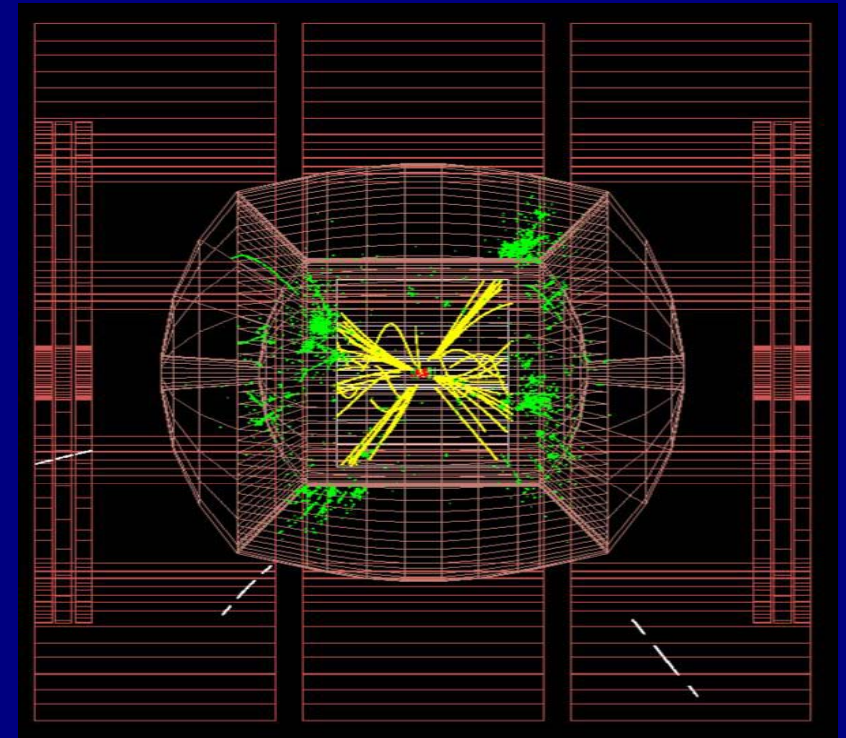
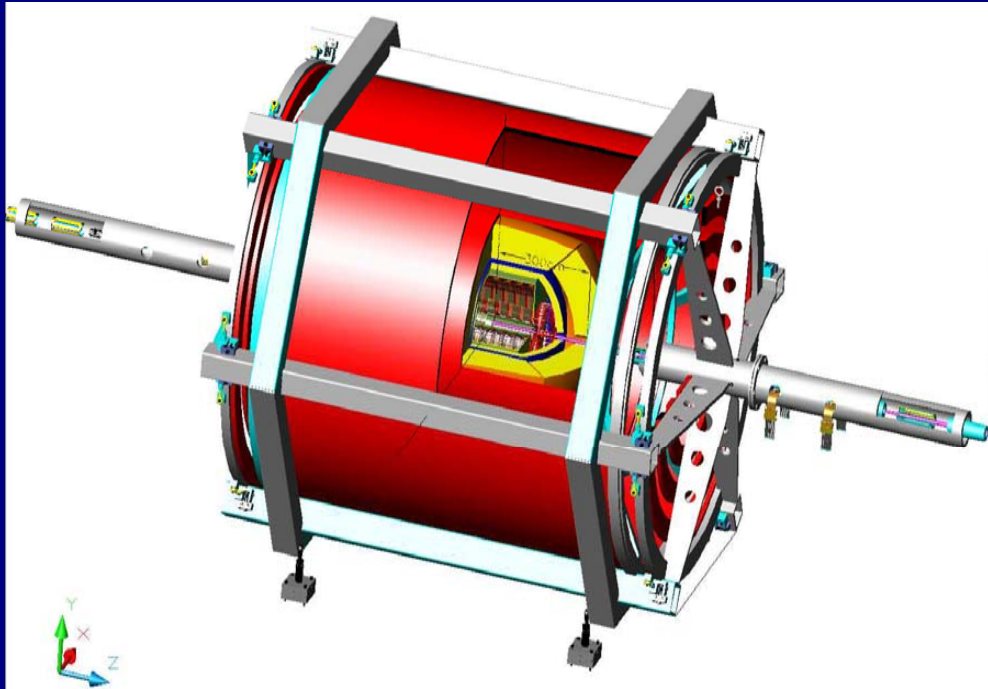
- b) What will the lines of supervision be, that is, for each student, to what extent do you, Marcel, and Corrado have the authority to tell that student what to work on, which approach to take, and so forth. If some students are working for both you and Marcel, who has first call on what percentage of their work time.
- c) Connected with the lines of supervision are responsibilities: Who is responsible for guiding the student's work here, for making sure the student does not "go off the deep end" in the work, for setting standards for the student to convey and document results, and for evaluating (at some point) the success or failure of that work.

Mark Fischler
Amber Boehnlein
Bob Tschirhart

The short (about two months) experience we had in Autumn 2006 with Marcel Demarteau was very successful and we would very much like to keep the same way of proceeding, if possible. Basically, the main directions, decisions and guidance of the project should be discussed among the people interested (namely, G.P., Marcel, Corrado, and to some extent, the groups of Paris VI and Valencia), but the software/technical supervision should rely on Corrado. ILCroot and the simulation software are an extremely powerful system, but great care is necessary in implementing an algorithm or a simulation inside the framework. G.P. is responsible for coordinating and making sure that the project will be successful.

- d) What are the proposed roster of students, funding arrangement, and split (if any between CD and Marcel -- the original memo discusses this and could just be copied forward, but we need clarity on what Marcel is going to fund (whether or not we add effort) and how much we will be funding.
 - 1. INFN and University of Lecce will provide salaries to the Italians involved
 - 2. Fedor has a fellowship from Novosibirsk
 - 3. Per diem, travel expenses, housing and transportation (assuming a rented car) should be provided by Fermilab
 - 4. The agreement with Marcel is that he would fund with \$15,000 the expenses for a software project more specific to his field of interest (VXD or a Si Tracker).
 - 5. Paris VI and Valencia have their own funds for sending their students to Fermilab in the case they are willing to continue to be part of the project.

Dual Readout/Dual Solenoid Detector for Physics Studies at μ Collider & CLIC



Modification of 4th Concept Detector for 3 TeV Physics

1. Vertex Detector 20-micron pixels
2. Silicon Tracker (preliminary version)
3. Forward Tracker Disks (preliminary version)
4. Triple-readout calorimeter
5. Dual-solenoid with Muon Spectrometer

} Replaces a Drift Chamber

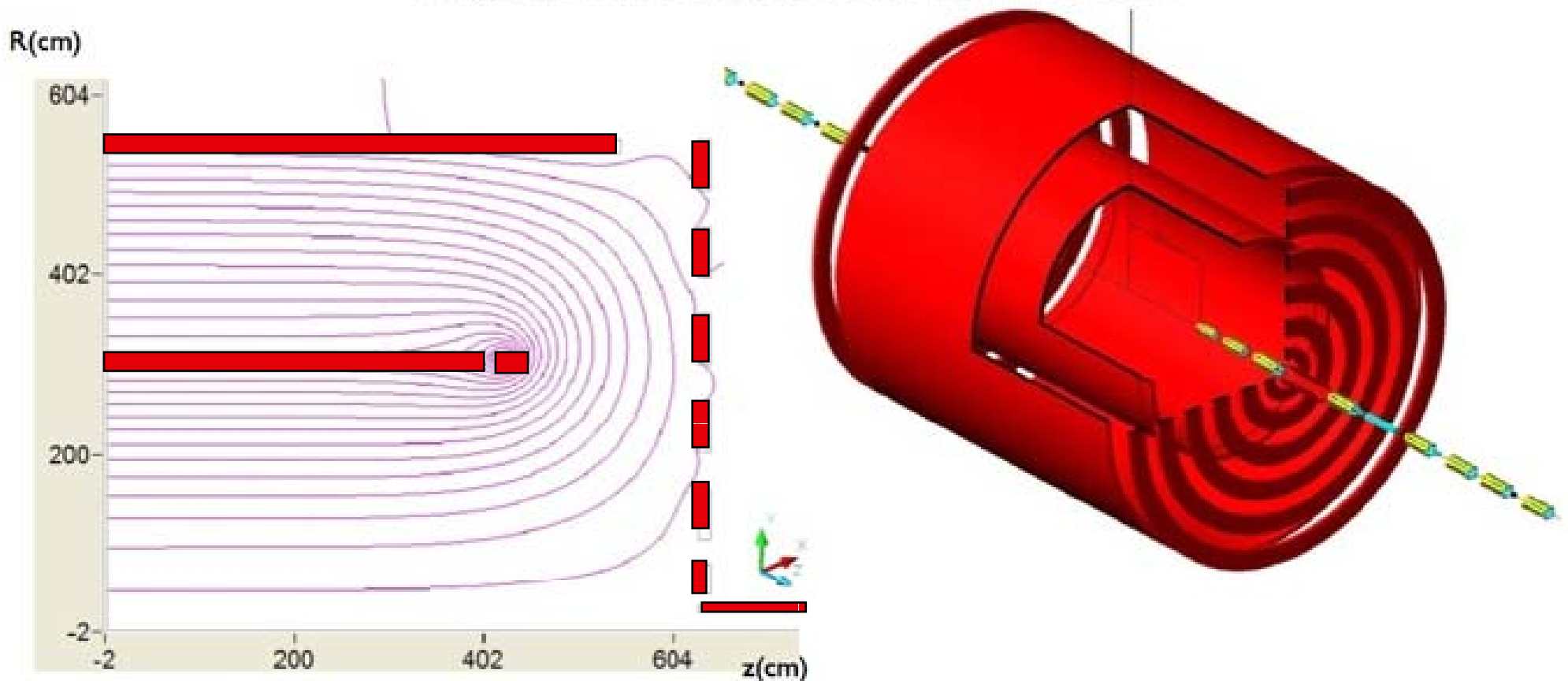
New magnetic field, new ``wall of coils'', iron-free:
many benefits to muon detection and MDI,

Alexander Mikhailichenko design

R. Yamada, Fermilab

M. Wake, KEK

Magnetic field of dual solenoid and wall of coils



Software



ILCroot

- based on ALICE ALroot
- Single Framework

generation, simulation, reconstruction, analysis

www.fisica.unile.it/~danieleb/ilcRoot

ilc.fnal.gov/detector/rd/physics/detsim/ilcroot.shtml

cd-amr.fnal.gov/ilc/ilcsim/ilcsim-grid.shtml

Large scale Grid Computing at Fermilab

Vertex Detectors

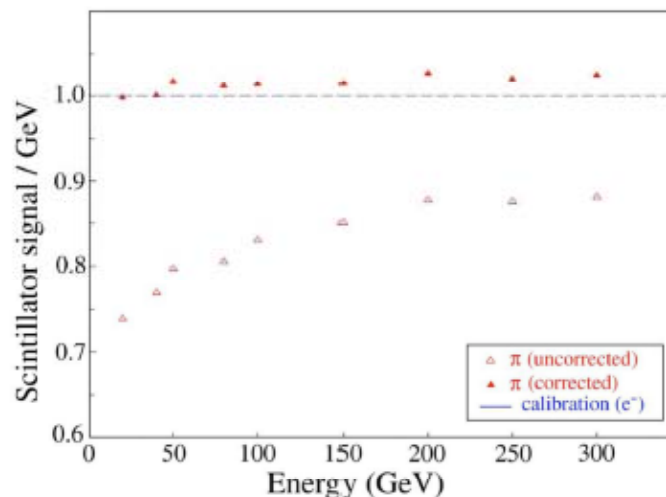
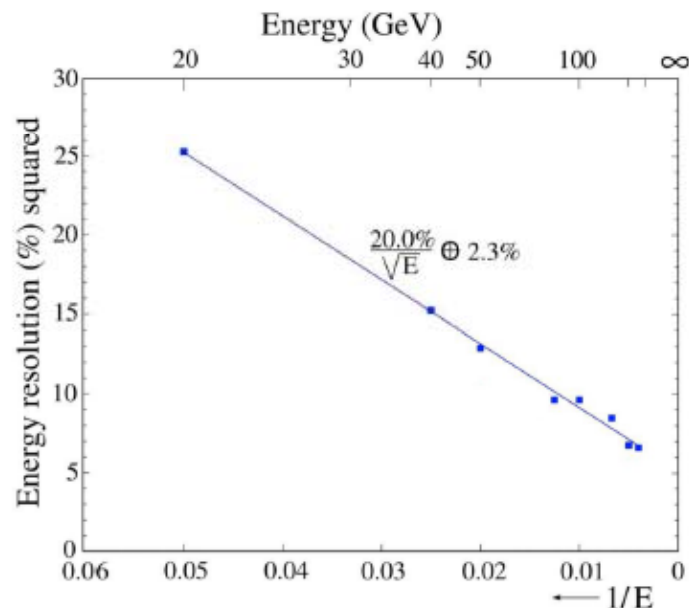
Tracking Options : TPC, SiT, CluCou, Pixel

Dual/Triple Readout Calorimeters

Dual Solenoids

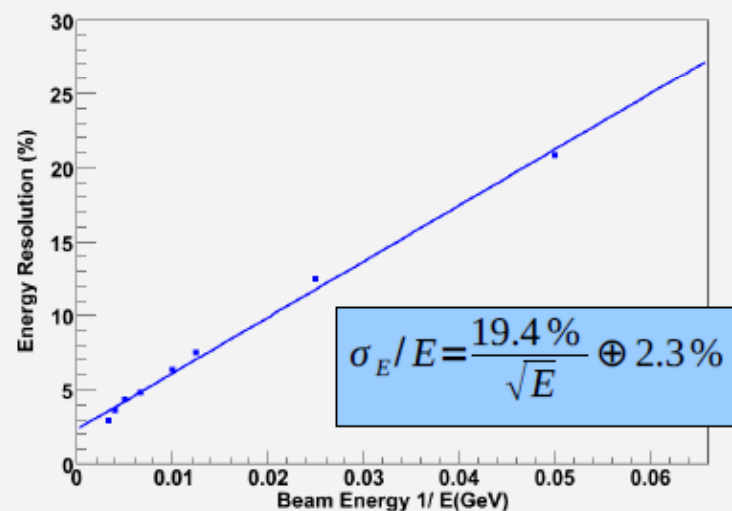
Muon Detector

Energy resolutions for pions (calibrated energy)

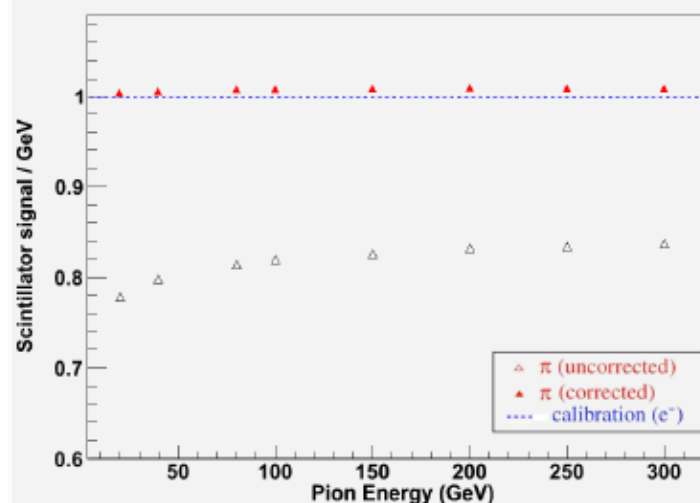


**DREAM
data**

DREAM Energy Resolution for pions (simulation)

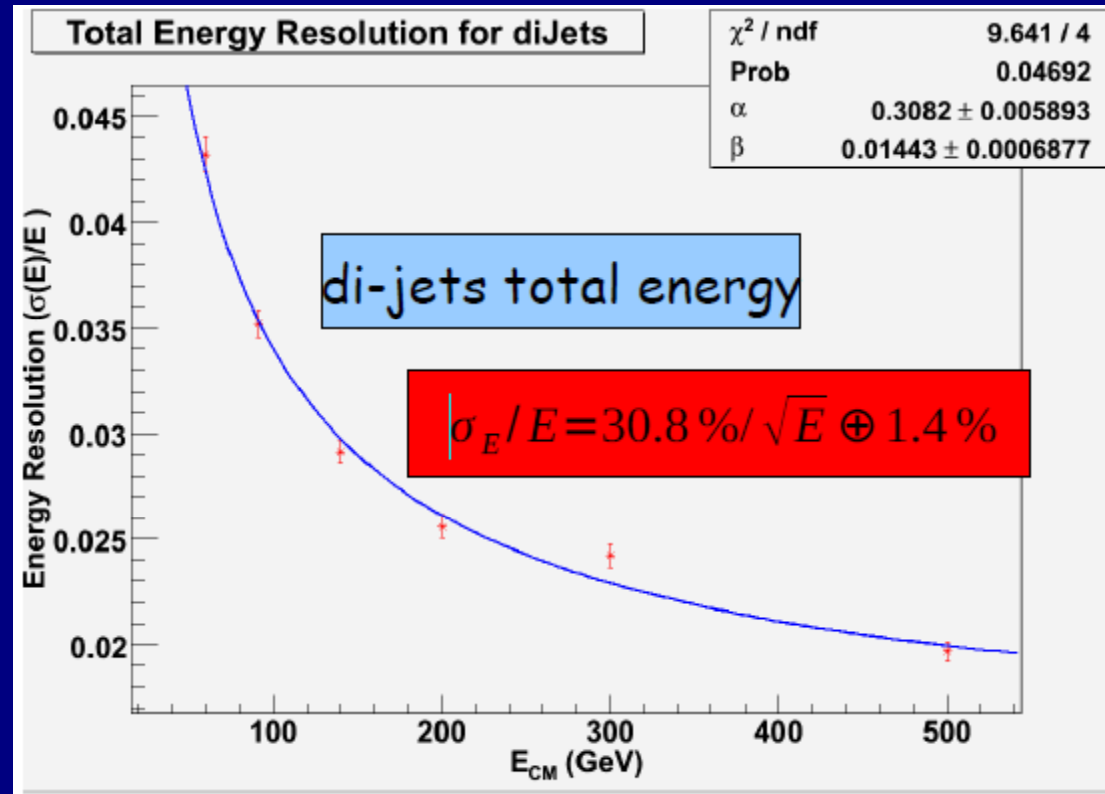
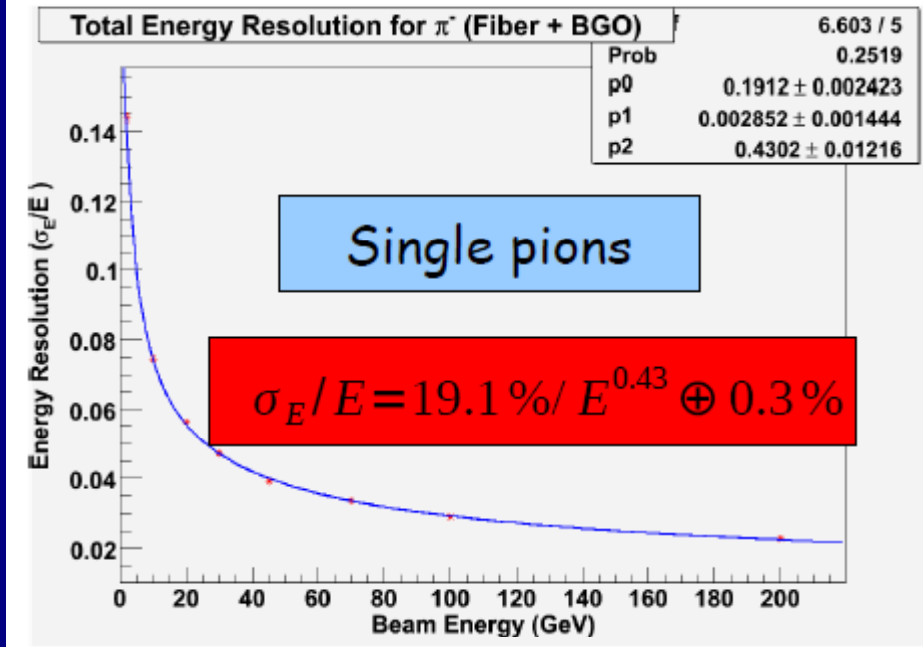
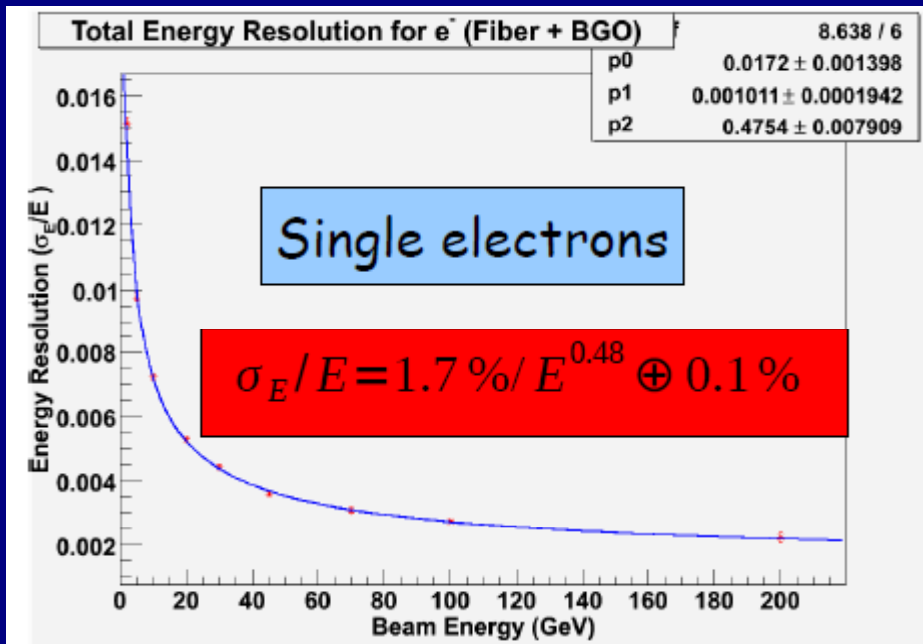


DREAM Energy Response (simulation)



**ILCroot
simulation**

DREAM & 4th Concept Dual Readout Calorimeter



WW Scattering (MC)

Only signal present in the analysis

Channel	Number of events	Generator
$\mu^+ \mu^- \rightarrow W^+ W^- \nu_\mu \bar{\nu}_\mu \rightarrow q \bar{q} q \bar{q} \nu_\mu \bar{\nu}_\mu$	~5000	Pythia 6.4.16
$\mu^+ \mu^- \rightarrow Z^0 Z^0 \nu_\mu \bar{\nu}_\mu \rightarrow q \bar{q} q \bar{q} \nu_\mu \bar{\nu}_\mu$	~5000	Pythia 6.4.16

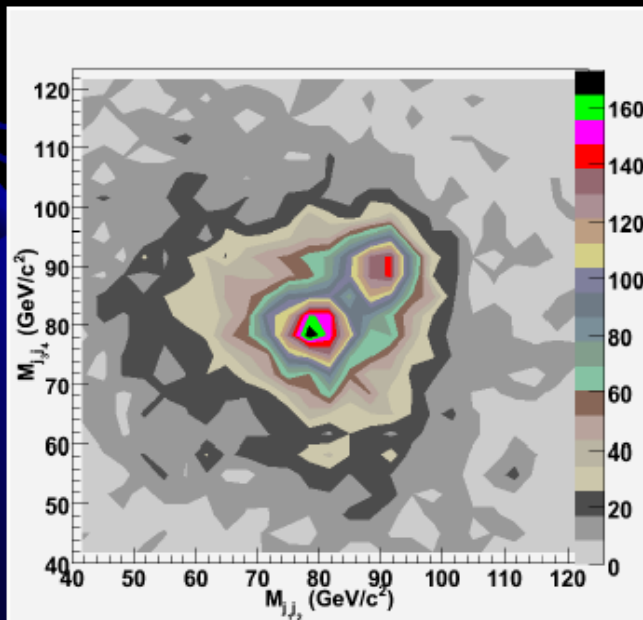
Event selection :

- Events forced into 4jets
- 4-jets finding efficiency: 98%

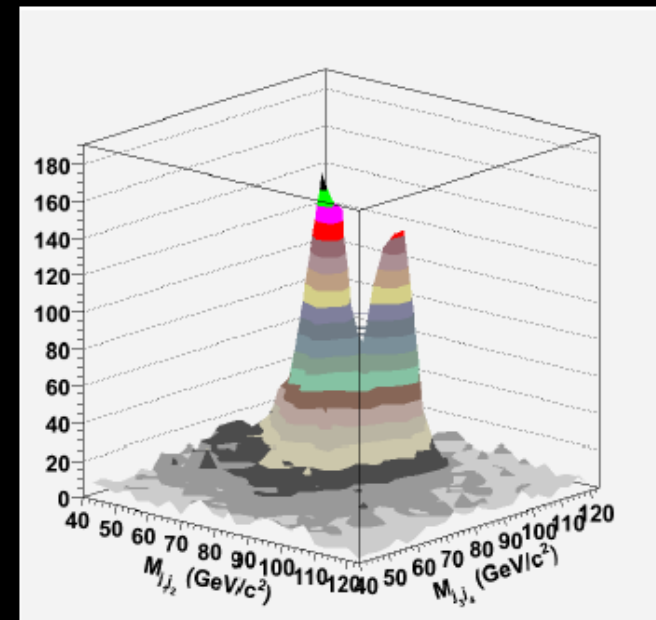
Jet pairing :

All pairs

All combinations plotted (3 entries/event)



Preliminary



November 11st, 2009

A. Mazzacane

19

Clear separation between the W and Z peaks obtained with full reconstructed events

**Preliminary studies of the
production of a single Z^0 in a fusion
process $\mu^+\mu^- \rightarrow \nu_\mu \bar{\nu}_\mu Z^0$**

using ILCroot

Background studies

Vito Di Benedetto

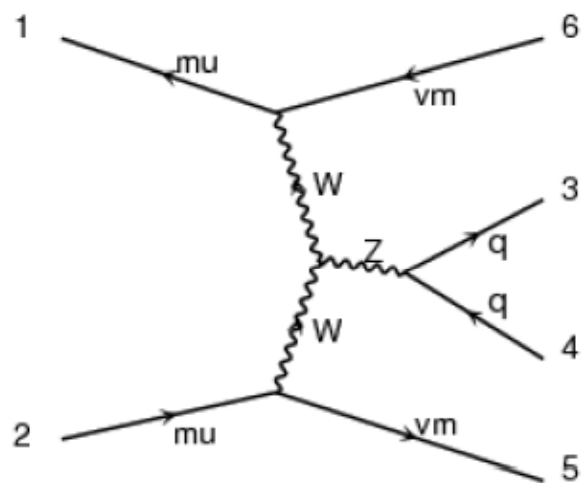
INFN Lecce and Università del Salento

Muon Collider Physics and Detector Meeting

December 15, 2010

Fermilab

Physics motivation



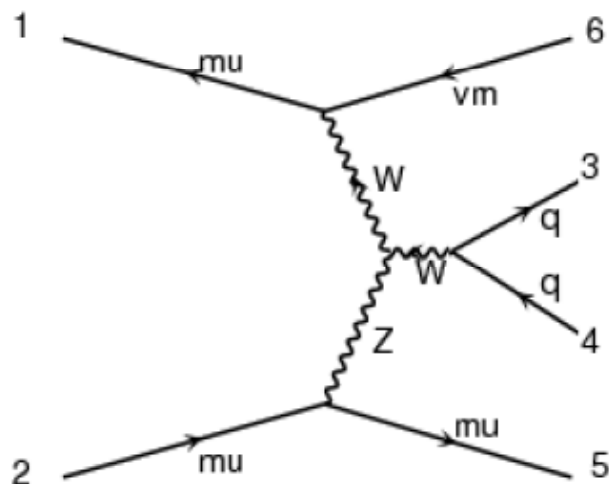
$$\mu^+ \mu^- \rightarrow \nu_\mu \bar{\nu}_\mu Z^0 @ 1.5 \text{ TeV}$$

jet, jet

Jet's are
originated by light
quarks (u,d,s)

- **Reconstruct Z^0 mass by jets**
- **Stress calorimeter energy resolution**
- **Tracker performances**

Physics motivation



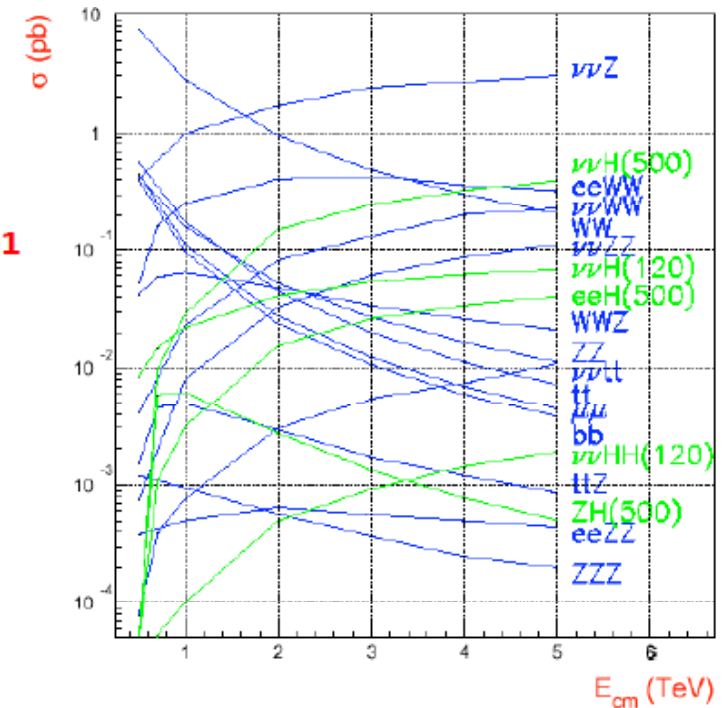
$$\mu^+ \mu^- \rightarrow \bar{\nu}_\mu W^+ \mu^-$$

└─► jet, jet

- **Reconstruct W^+ mass from jets**
- **In case μ^- isn't tagged, W^+ in this channel can mimic a Z^0**
- **Stress calorimeter energy resolution**
- **Tracker performances**

Physics environment

- $\sigma(\mu^+\mu^- \rightarrow \nu_\mu \bar{\nu}_\mu Z^0) = 4.1089 \text{ pb}$
- $\mu\text{C Luminosity @1.5TeV} = 0.8 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- I simulated 9900 events (It is ~ 3.5 days of data taking)

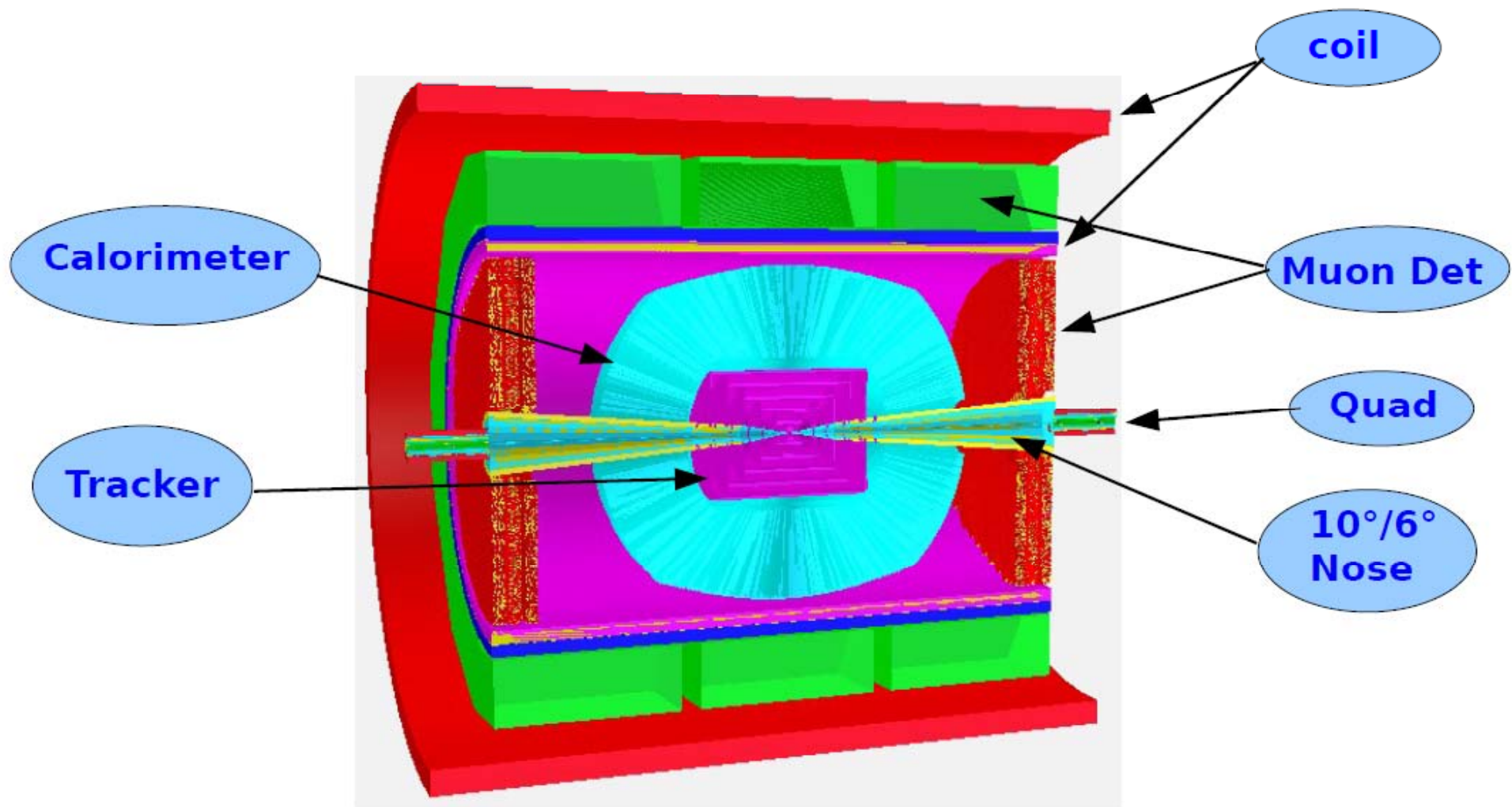


ILCroot: **root** Infrastructure for **L**arge **C**ollider

- Software architecture based on ROOT, VMC & Aliroot
- Uses ROOT as infrastructure
 - All ROOT tools are available (I/O, graphics, PROOF, data structure, etc)
 - Extremely large community of users/developers
- Include an interface to read MARS output to handle the MuonCollider background
- **Single framework**, from generation to reconstruction through simulation. Don't forget analysis!!!
- It is Publicly available at FNAL on ILCSIM since 2006

All the studies presented are performed by ILCRoot

Detector baseline



Simulating MARS event

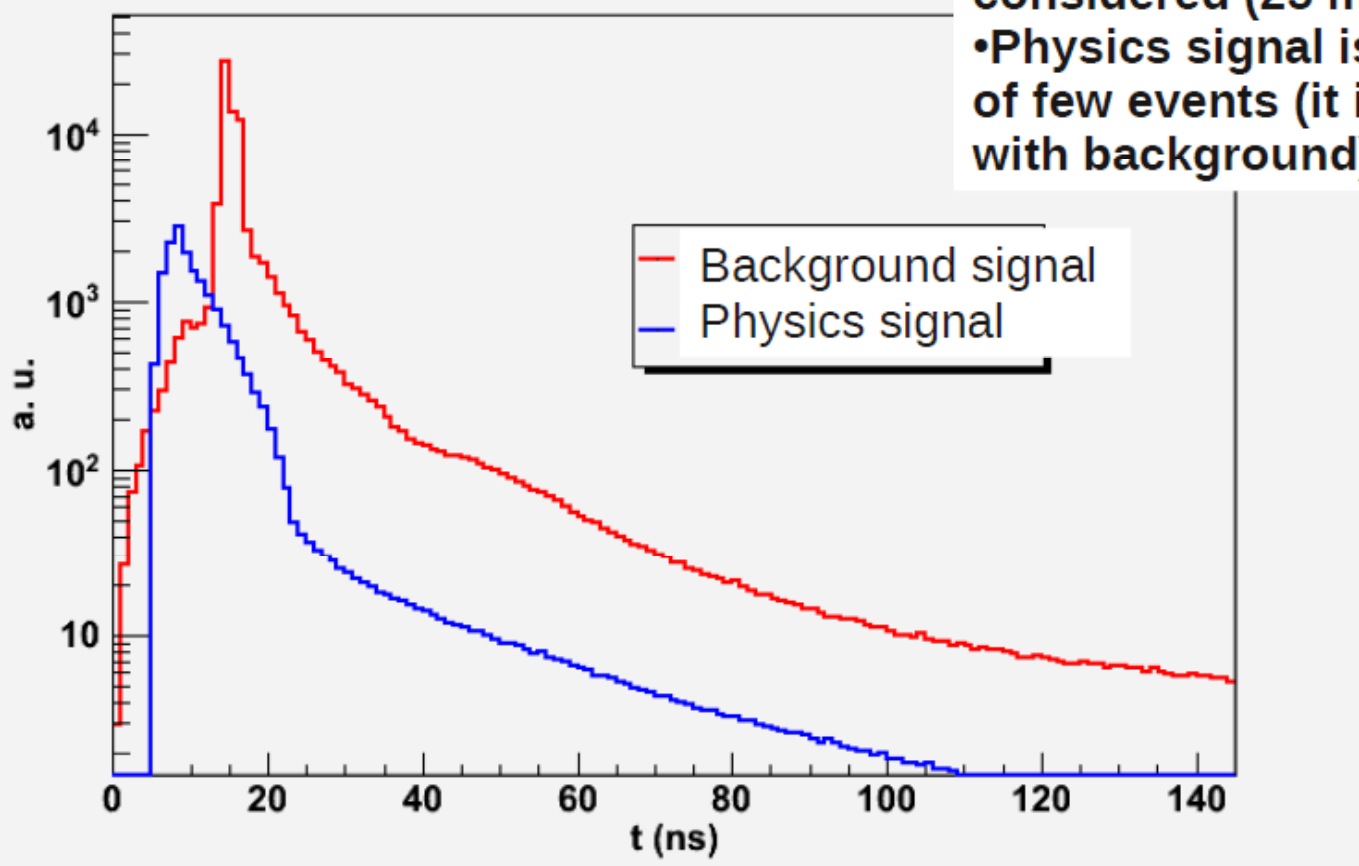
- **Simulated 1 MARS event**
 - **Origin of the particles: cone**
 - **Background particles files for μ^+ and μ^- within 25 m and beyond 25 m**
 - **Particle in a MARS event $\sim 1 \times 10^8$, almost all originated within 25 m**
 - **Particles from file within 25 m have weight ~ 20**
 - **These particles are split using azimuthal symmetry**
 - **Particles from file beyond 25 m have weight $\ll 1$**
 - **Pick up randomly these particle, taking care the integral weight is the same**
 - **This have been done 10 times, then the average signal have been used**

Simulating MARS event

- Time and disk space needed to simulate 1 MARS event using full geometry and full simulation
 - **Weighted particles:**
 - **1 CPU \leftrightarrow 200 h**
 - **150 Gb disk space**
 - **Unweighted particles;**
 - **1 CPU \leftrightarrow 2000 h**
 - **1 Tb disk space**
- Disk space and CPU time can be reduced using simplified geometry and fast simulation

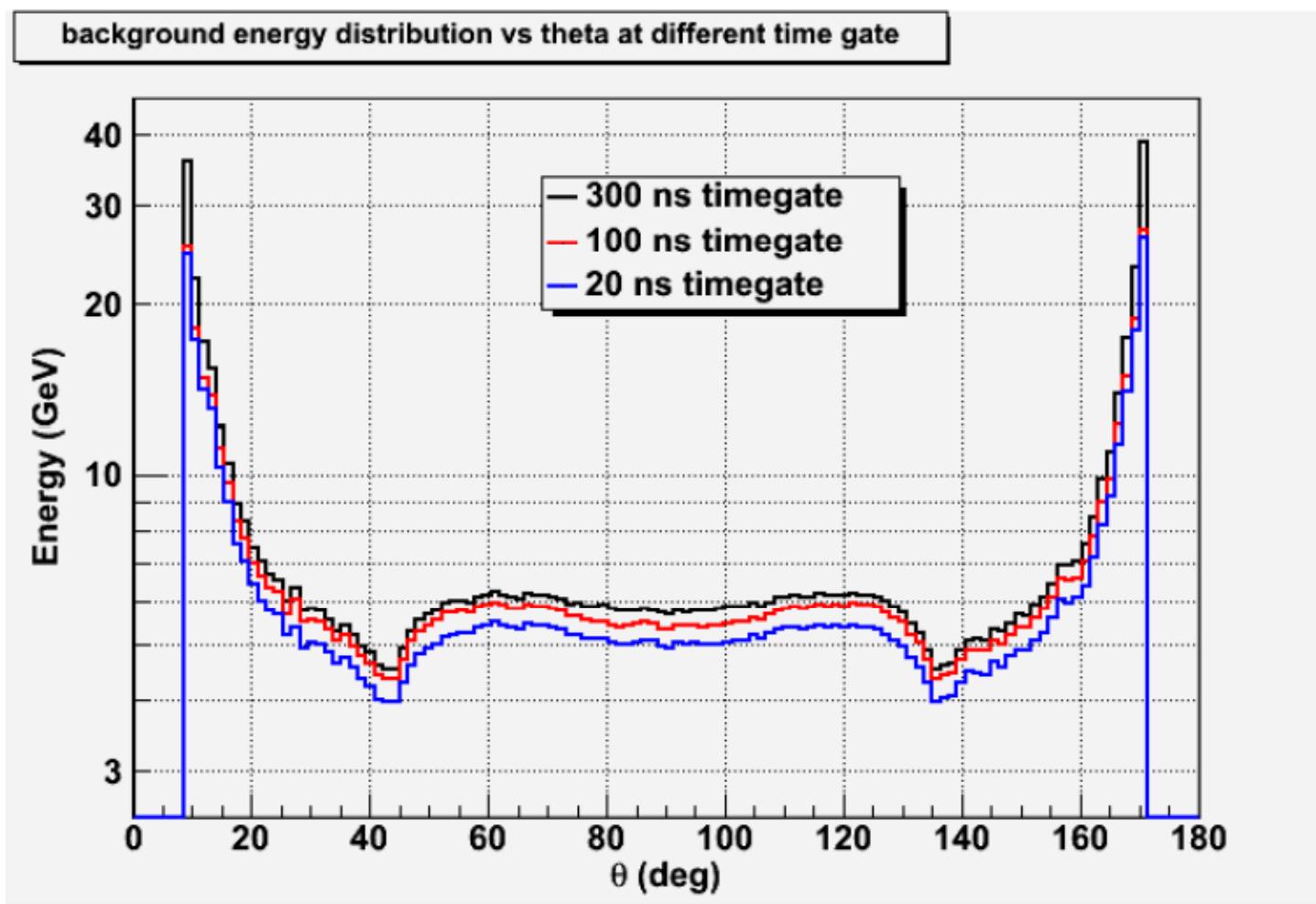
Timing of the Physics signal and background event

Signal and background timing

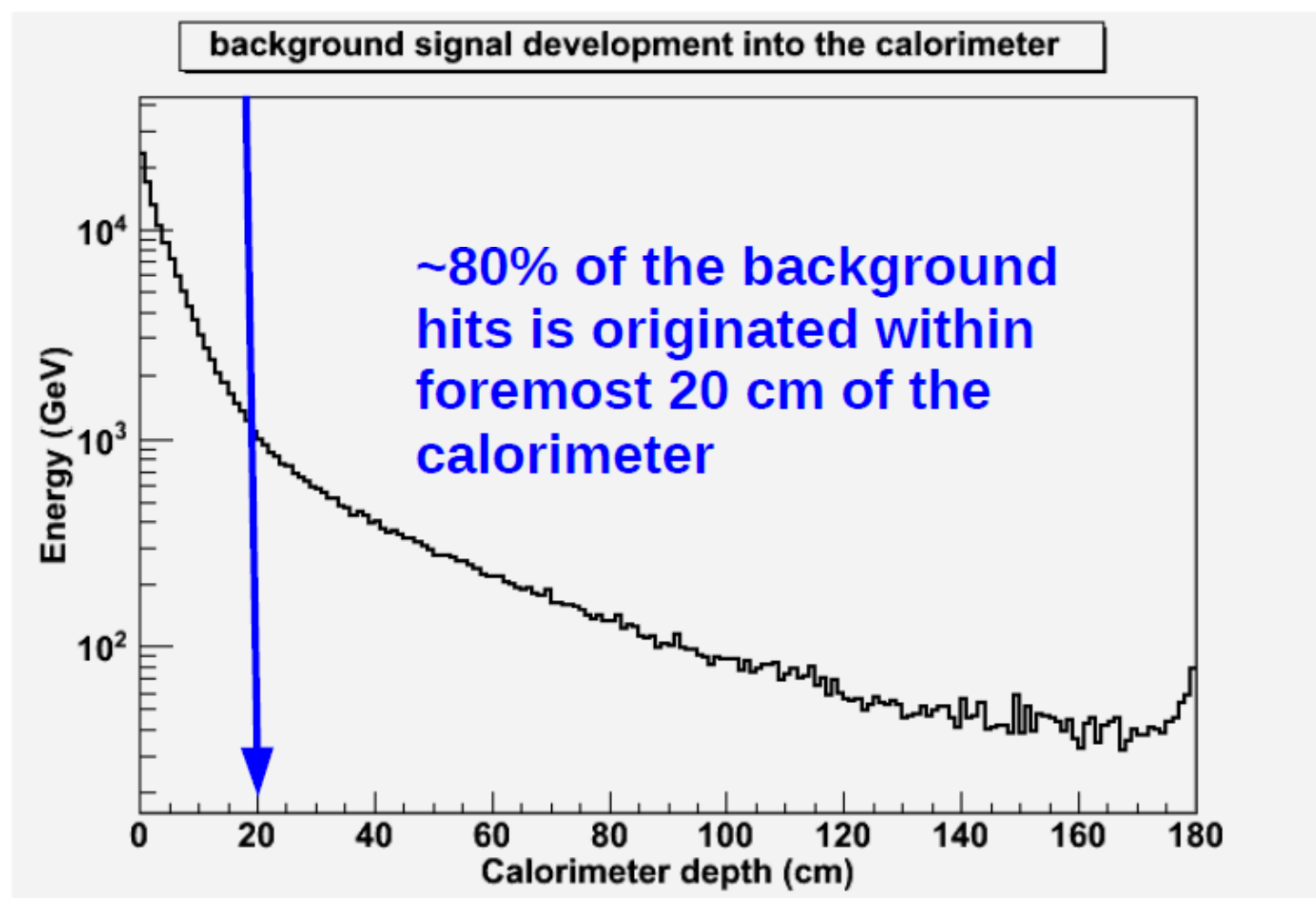


- Entire background considered (25 m + 250 m)
- Physics signal is an average of few events (it is not in scale with background)

background vs theta for different calorimeter integration time

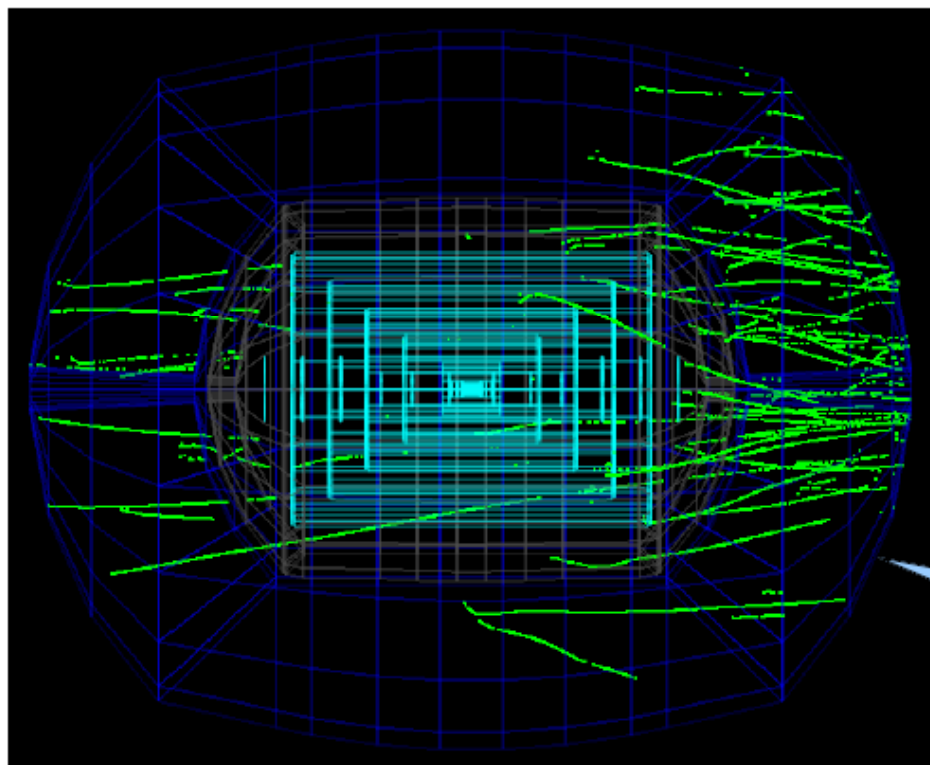
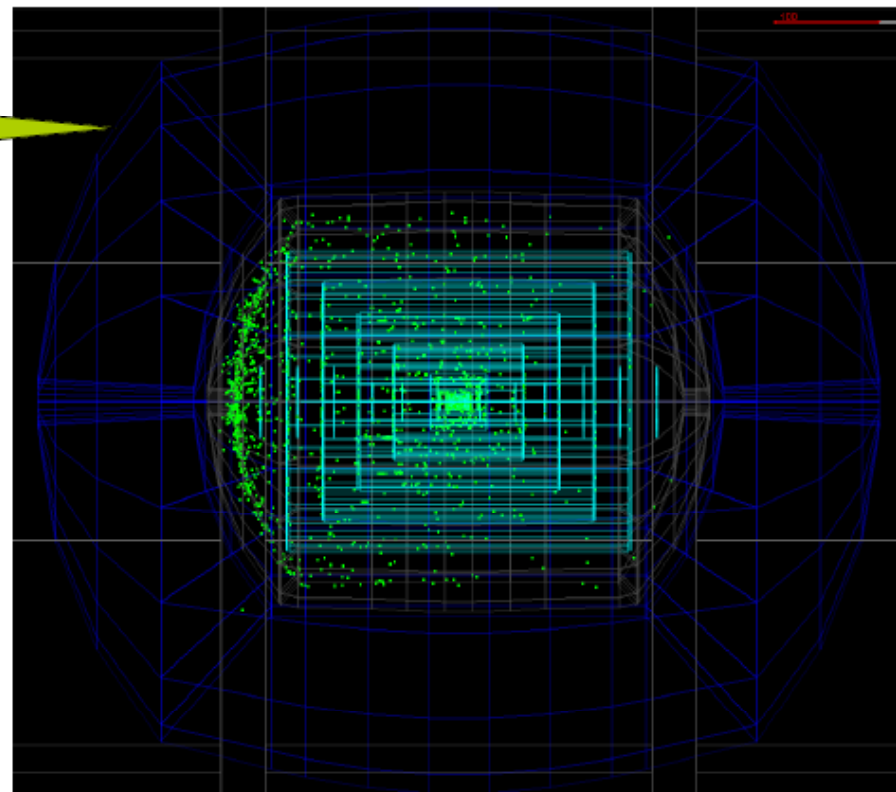


Development of the background event into the calorimeter



beam background effect in HCAL and ECAL

electrons background
effect

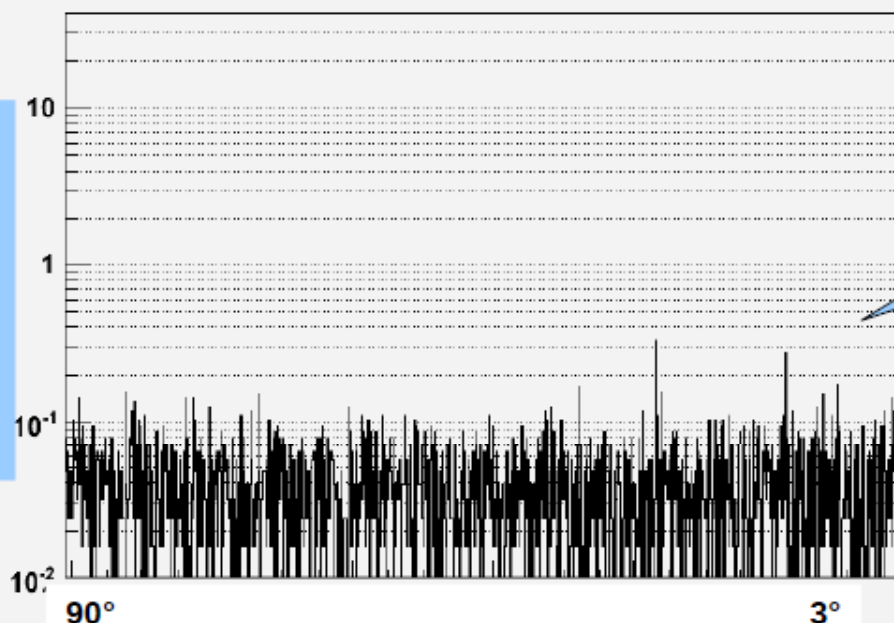


muons background
effect

Estimate beam background in HCAL and ECAL

HCAL

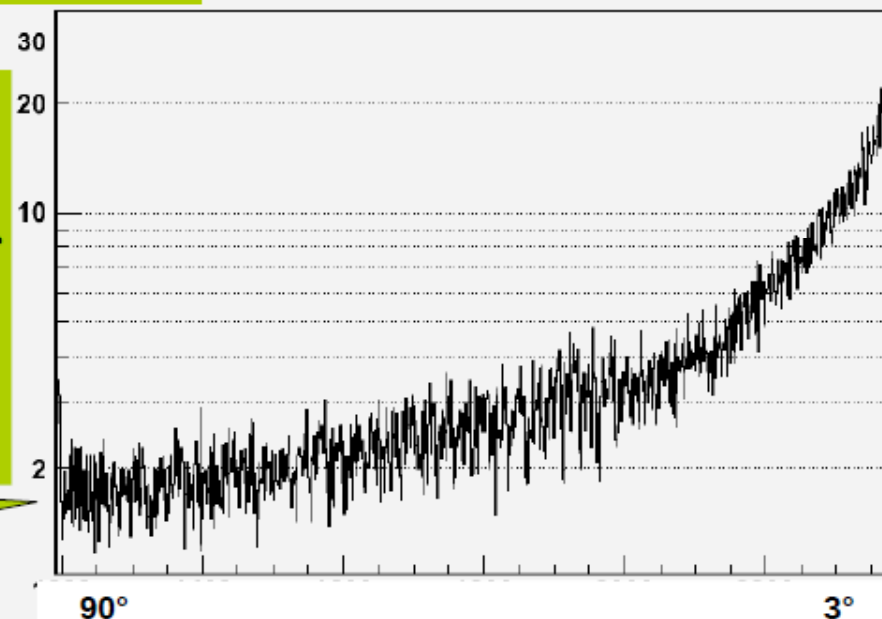
GeV/10 Towers



The HCAL background is mostly induced by muons

ECAL

GeV/40 crystals

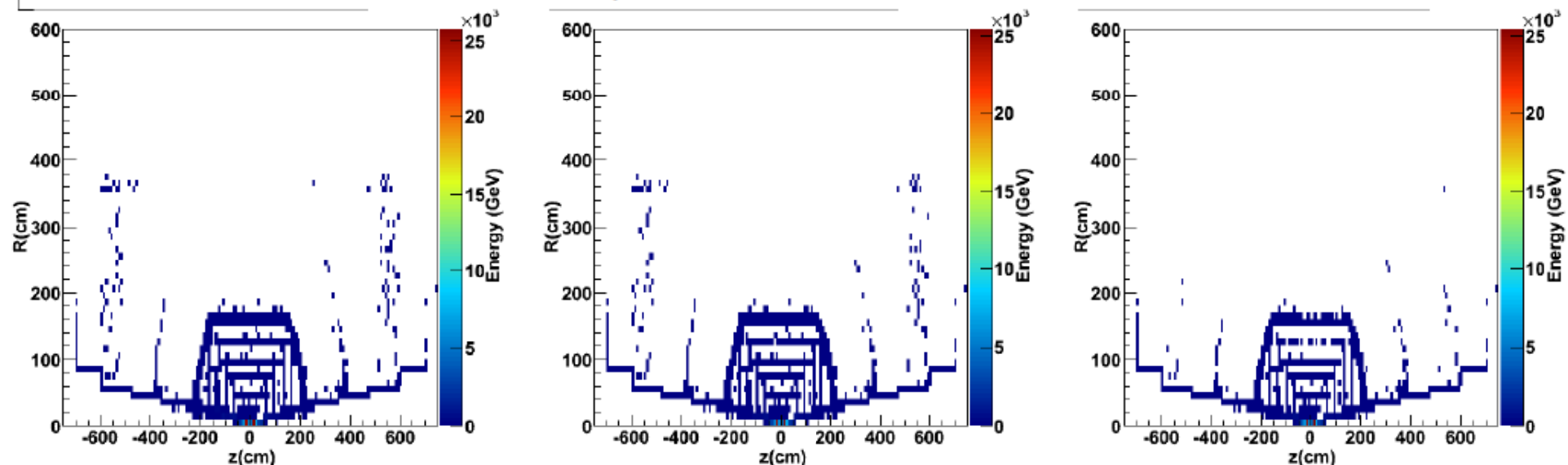


The ECAL background is mostly induced by electrons

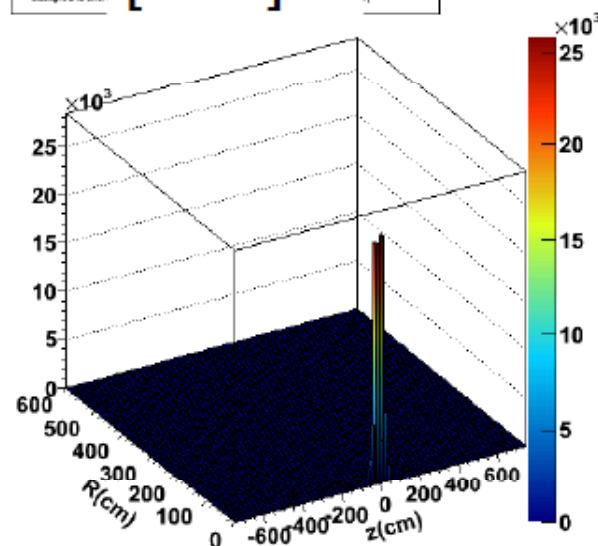
Origin of gammas that enter into the calorimeter.

MARS input file with background within 25 m.

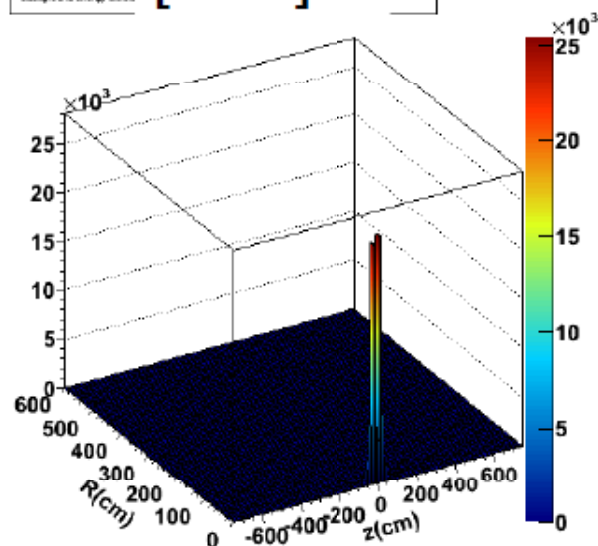
Each entries is the integrated energy in an area $10 \times 10 \text{ cm}^2$. If a particle reach the calorimeter from the nose, it don't make shower into the tracker



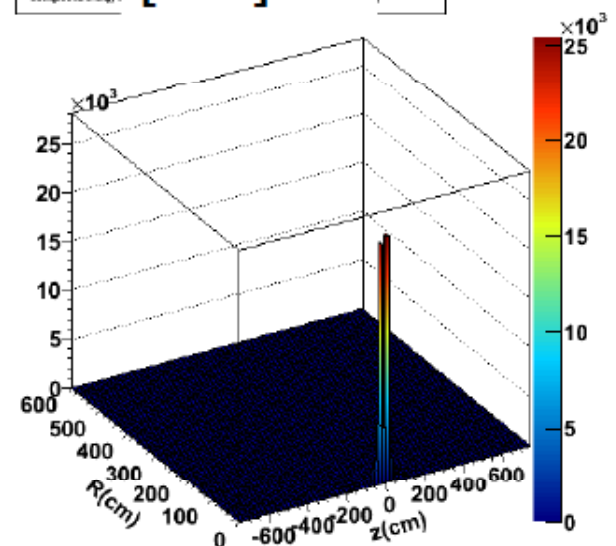
background ener [0-300]ns



background energy dist [5-105]ns

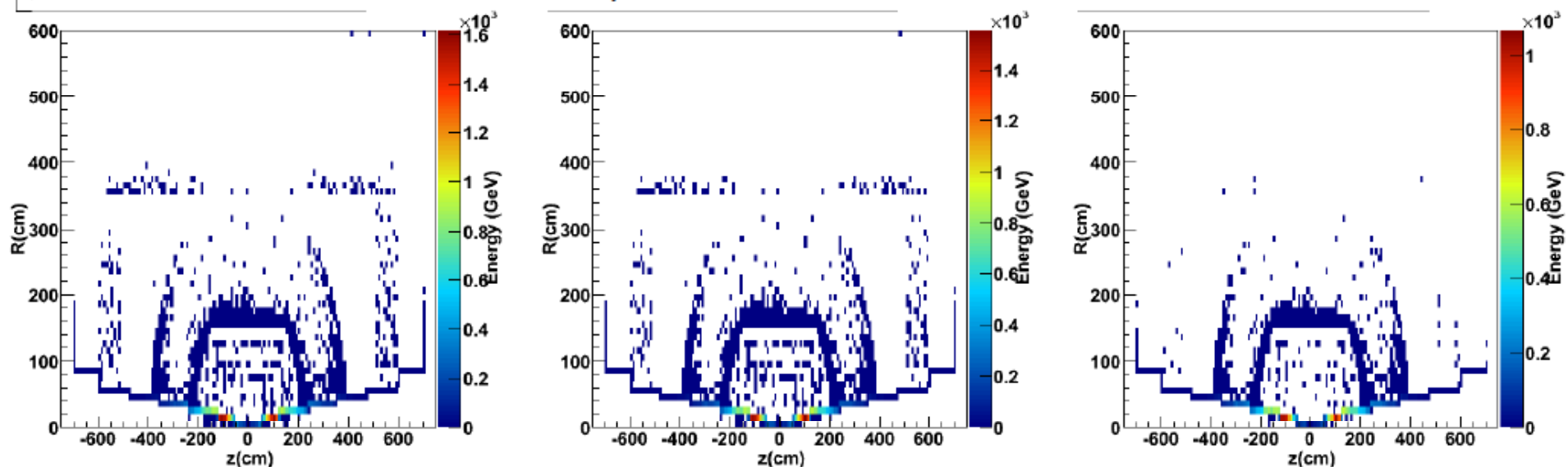


background energy [5-25]ns



Origin of neutrons that enter into the calorimeter. MARS file within 25 m.

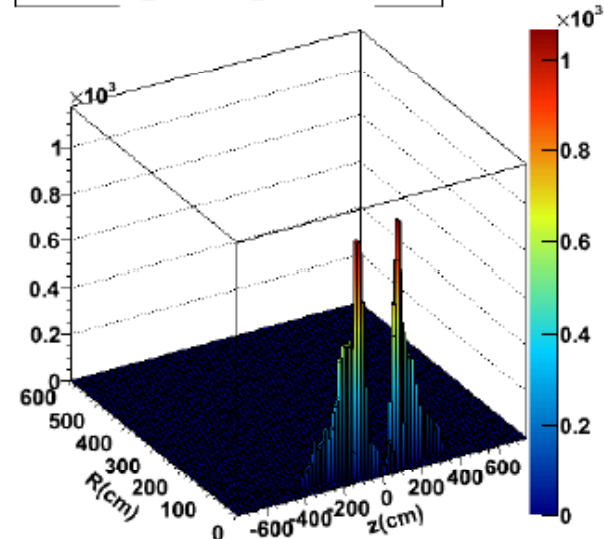
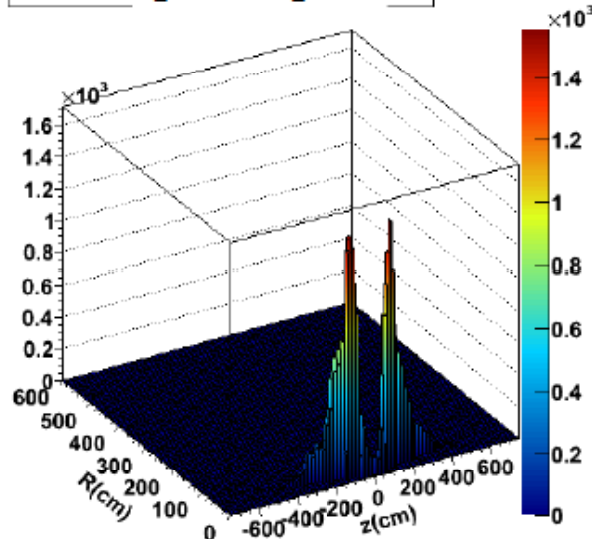
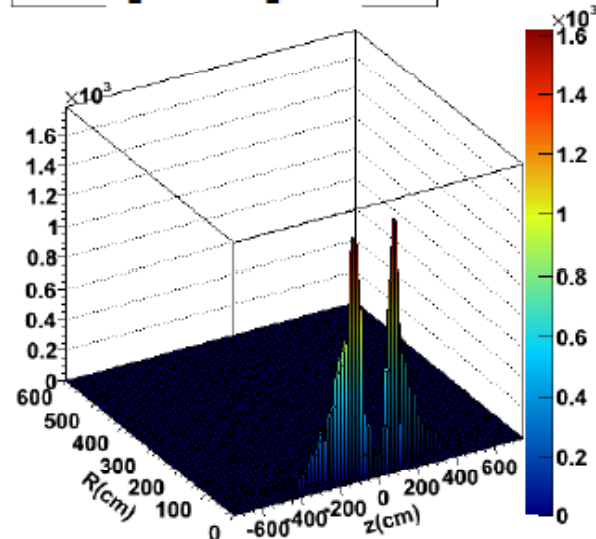
Each entries is the integrated energy in an area $10 \times 10 \text{ cm}^2$ If a particle reach the calorimeter from the nose, it don't make shower into the tracker



[0-300]ns

[5-105]ns

[5-25]ns

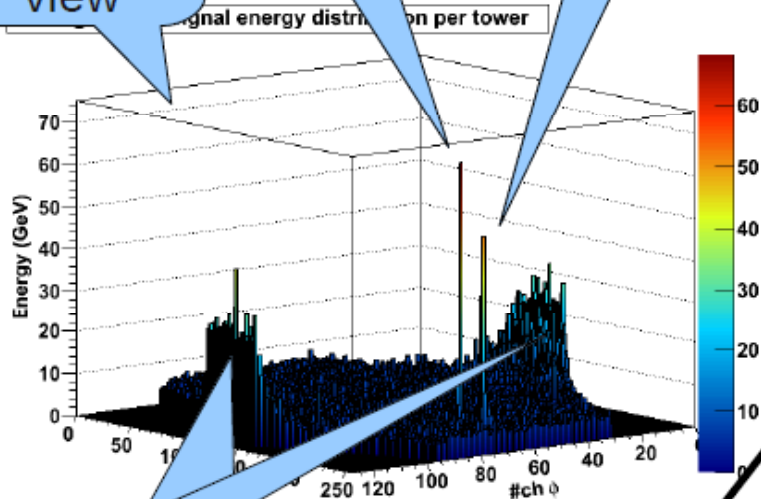


Z \rightarrow jj event with MuonCollider background Event 3

Full
calorimeter
view

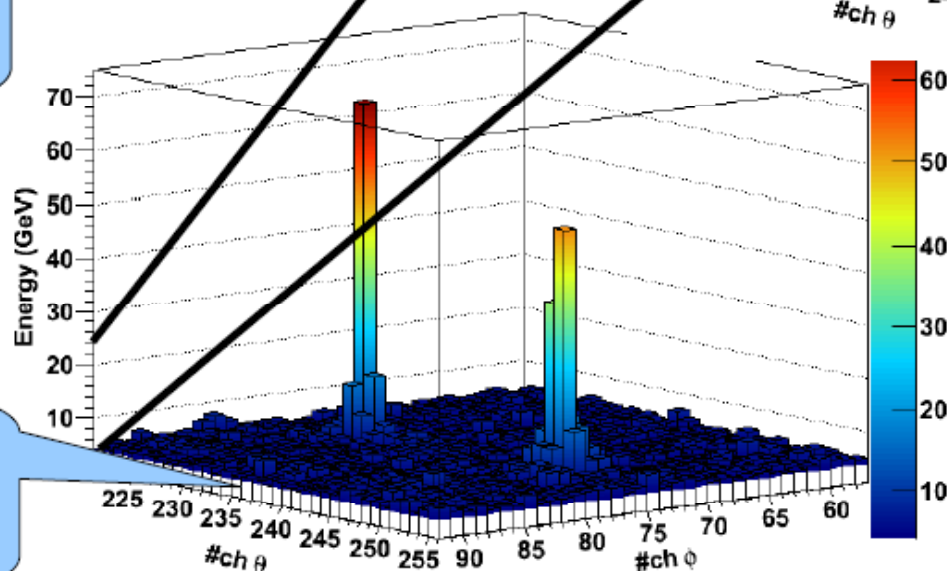
Jet1

Jet2



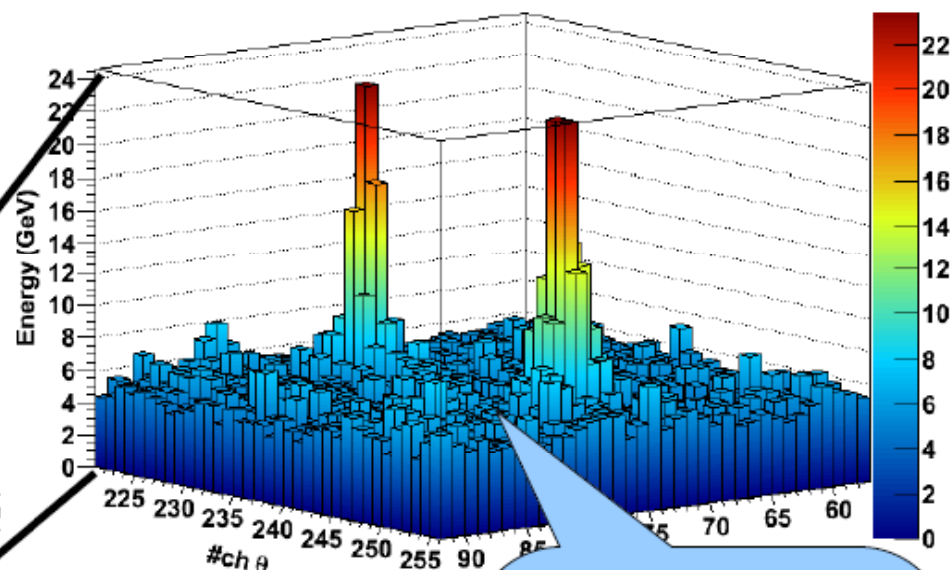
Background
pick
in endcaps

background + signal energy distribution per tower (zoom)



Zoom in
calorimeter
area of the jets

background + signal energy distribution per tower (zoom)



Zoom in
energy axis
to see the
background
fluctuations

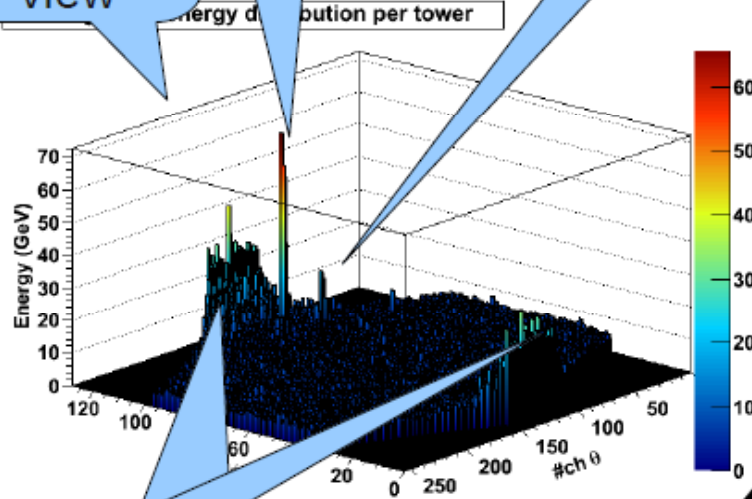
~200 GeV jet
~100 GeV jet

Z→jj event with MuonCollider background Event 8

Full
calorimeter
view

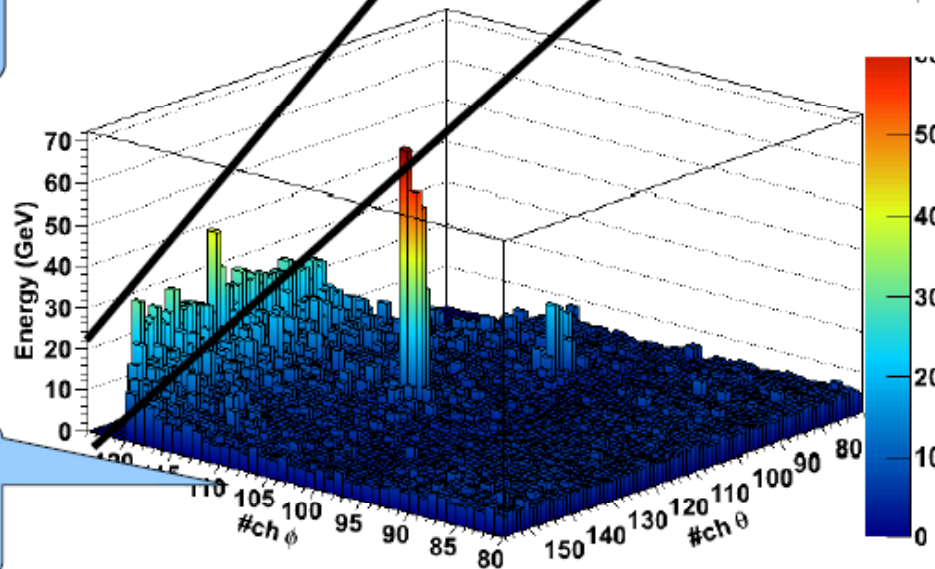
Jet1

Jet2



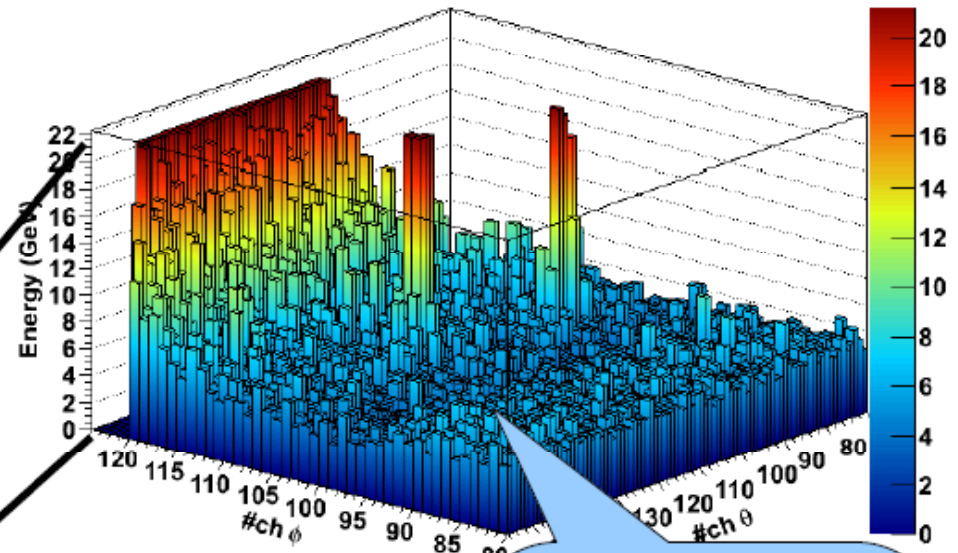
Background
pick
in endcaps

background energy distribution per tower



Zoom in
calorimeter
area of the jets

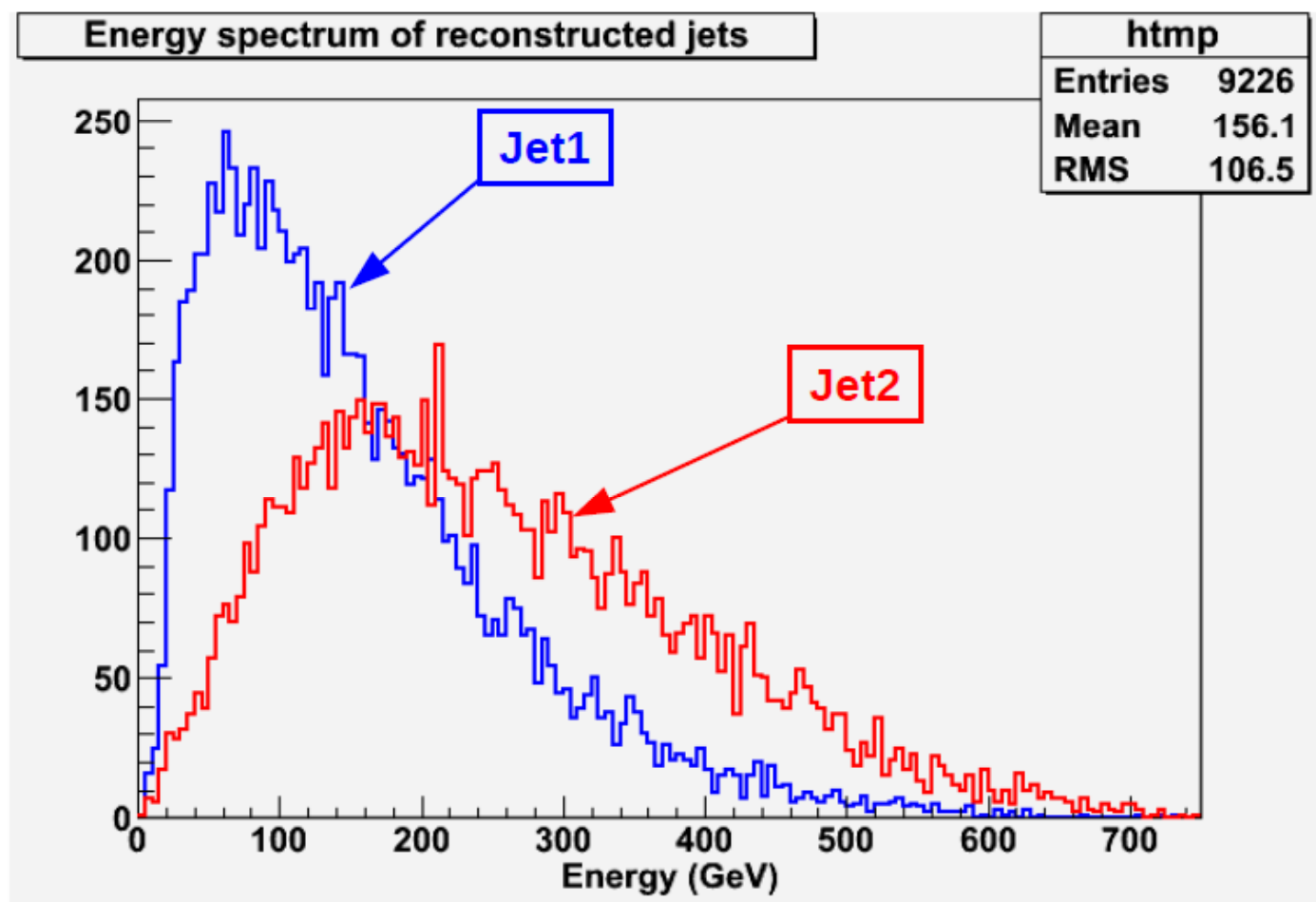
background energy distribution per tower



Zoom in
energy axis
to see the
background
fluctuations

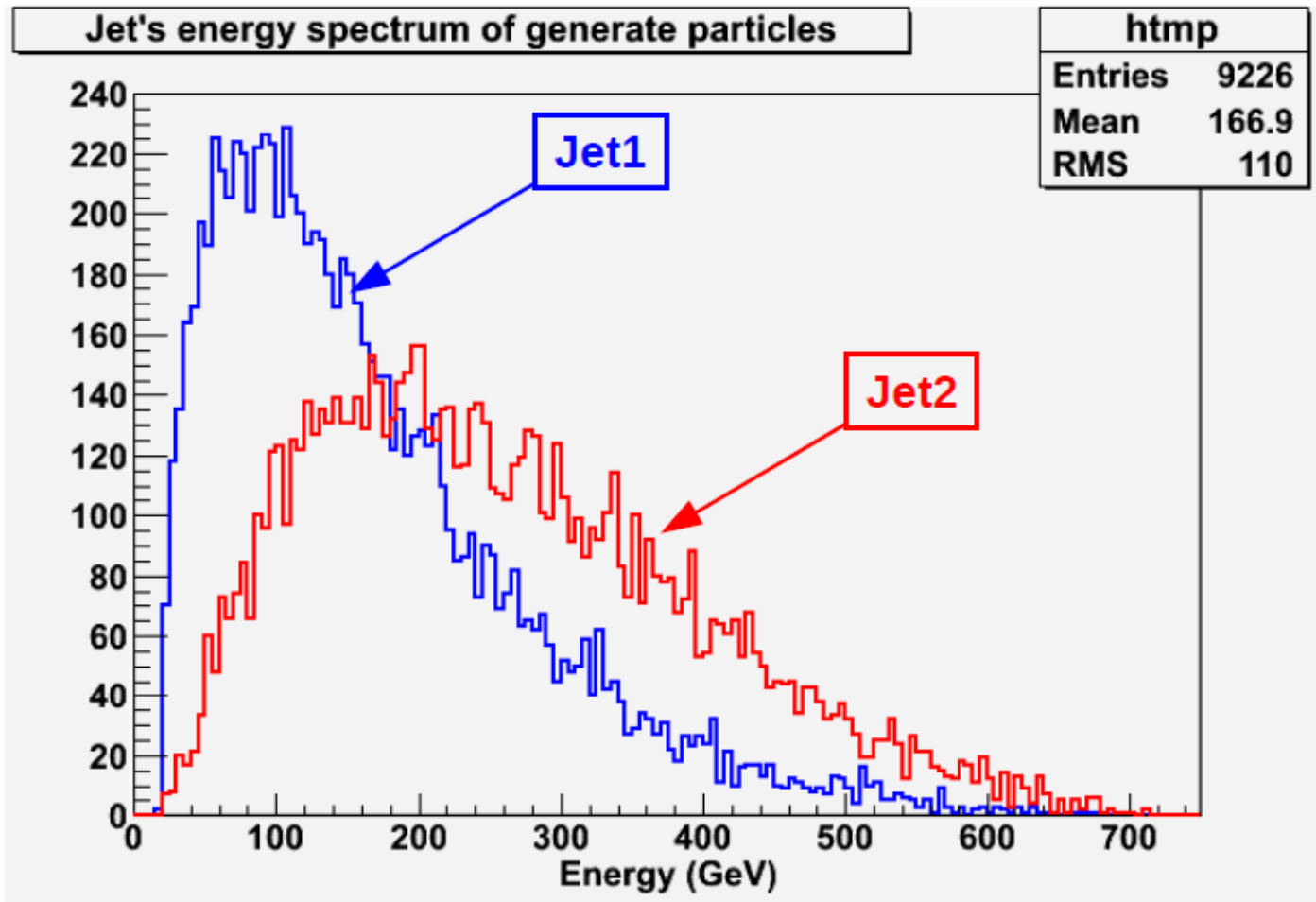
~250 GeV jet
~80 GeV jet

Reconstructed jets energy spectrum



Jet's energy spectrum of reconstructed jets
(bin = 5GeV) Pick between 100 – 200 GeV

MadGraph Generated particles informations



- Over 9900 event simulated I found 2 jets in 9226 events
- **93% jet reconstruction efficiency**
- Probably in 7% of the events one of the jets smash the nose

Jet's energy spectrum of generated particles
(bin = 5GeV)

Physics and background: some comment

- Jets develop in 16 – 25 towers; mean energy 150 GeV
- Background in barrel: mean energy 5 GeV RMS 0.6 GeV
Jet energy fluctuation after background pedestal cut
2.5 – 3 GeV
- Background in endcap $> 20^\circ$: mean energy 5 GeV RMS 1. GeV
Jet energy fluctuation after background pedestal cut
5 – 6 GeV
- Background in endcap $< 20^\circ$: mean energy 12 GeV RMS 5. GeV
Jet energy fluctuation after background pedestal cut
20 – 25 GeV

• Conclusion

- The best nozzle simulation and geometry so far
- Lowest secondary particles yield
- Minimal variation of the weight
- More parameters available
- Thanks to N. Mokhov and S. Striganov for help with MARS output file information

• Plans

- The plans were to run **ILCroot** for current MARS output file excl-8e4-pl to get hits in Tracker and VXD and look at hits occupancy

• Problem

- excl-8e4-pl nozzle geometry does not fit into geometry of the CLICCT (SiD Tracker Endcap + FTD) – there are overlaps with nozzle (next slides)
- The following is one of the nozzle geometry options having no overlaps
- Detailed nozzle geometry modifications study is underway
(N. Mokhov, S. Striganov, simulation in MARS)

ILCroot more users

ILCroot & FermiGrid ILC4C VO

Name	Site	VO: Name	# Jobs	Wall Time (h)	Delta Jobs	Delta Wall Time (h)
ILC						
Vito Di Benedetto	ALL	ILC4C	122590	212231.3	-620630	-815208.9
=====						
ILC						
Nikolay Terentyev	FNAL_GPGRID	ILC	246	91.6	+246	+91.6
Nikolay Terentyev	FNAL_GPGRID	ILC4C	28	27.5	+28	+27.5
+-----+-----+-----+-----+-----+-----+						
Nikolay Terentyev	ALL		274	119.1	+274	+119.1

Procedure to run ILCroot for the Muon Collider Detetor simulaion on the ilcsim

- login to ilcsim.fnal.gov using your own account
- set up the fundamental for running ilcroot
 - ilcsim.fnal.gov> ./grid/fermiapp/ILCroot/sw/ILCroot/setup_ILCrootMuXDetV2.sh
- If this is your first doing this you need to copy the file .rootrc over to your own home area.
 - ilcsim.fnal.gov> cp \$ILC_ROOT/.rootrc ~/
- A quick exercise to run for one mu mu -> ZH event
 - Note that this will create a lot of files beside the files that you will copy over.
So you might want to create a subdirectory and change directory to it before you go ahead.
Such as
 - ilcsim.fnal.gov> mkdir my_exercise
 - you can replace the name "my_exercise" to be your preference
 - ilcsim.fnal.gov> cd my_exercise
 - ilcsim.fnal.gov> cp ~chenyc/zh_gen/ZH120_ECM1500.txt .
 - This contains 1000 events generated by Pythia 6.4.24.
 - ilcsim.fnal.gov> cp ~chenyc/zh_gen/Config.C .
 - ilcsim.fnal.gov> cp ~chenyc/zh_gen/sim.C .
 - ilcsim.fnal.gov> cp ~chenyc/zh_gen/rec.C .
 - ilcsim.fnal.gov> ilcroot
 - ilcroot> .x sim.C
 - By default this runs with only one event.
 - If you want to run more you could try ".x sim.C(3)" for example.
 - ilcroot> .q
 - Remember to quite here. The ilcroot will run into unexpected trouble if continue to the next step without taking a break here.
 - ilcsim.fnal.gov> ilcroot

Volume 578
December 29, 1989

THE FOURTH FAMILY OF QUARKS AND LEPTONS^a

Second International Symposium

Editors

DAVID B. CLINE and AMARJIT SONI

Conference Organizers

DAVID B. CLINE, JIM KOLONKO, and AMARJIT SONI

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^aThese papers are the result of a conference entitled Second International Symposium on the Fourth Family of Quarks and Leptons held on February 23-25, 1989 in Santa Monica.

First CDF Top Search
presentation,
2/23/1989
Results surpassed
UA1, UA2.



Beyond 500 GeV ILC

Search for Heavy Top $t' \rightarrow Wq$
in Lepton Plus Jets Events in $\int \mathcal{L} dt = 4.6 \text{ fb}^{-1}$

The CDF Collaboration

March 5, 2010

Abstract

We search for pair production of the heavy top (t') quarks pair decaying to Wq final states using 4.6 fb^{-1} data sample of lepton+jets collected using inclusive lepton and met+jets triggers.

We reconstruct the mass of the t' quark (M_{rec}) and perform a two dimensional-fit of the observed (H_T, M_{rec}) distribution to discriminate the new physics signal from Standard Model backgrounds. We exclude a Standard Model fourth-generation t' quark with mass below 335 GeV at 95%CL.






Four Statements about the Fourth Generation

B.Holdom, W.S.Hou, T.Hurth, M.L.Mangano, S.Sultansoy, G. Unel

(Submitted on 30 Apr 2009 (v1), last revised 25 Sep 2009 (this version, v2))

This summary of the Workshop "Beyond the 3-generation SM in the LHC era" presents a brief discussion of the following four statements about the fourth generation: 1) It is not excluded by EW precision data; 2) It addresses some of the currently open questions; 3) It can accommodate emerging possible hints of new physics; 4) LHC has the potential to discover or fully exclude it.

Fourth Generation

-  [1 - Phenomenology](#)
-  [2 - Phenomenology - Conference Proceedings](#)
-  [3 - Phenomenology - Models](#)
-  [4 - Theory - Models](#)
-  [5 - Theory - Models - Conference Proceedings](#)

http://www.nu.to.infn.it/Fourth_Generation

$M_{t'}$ Threshold scan,

CPV, BAU
 $Y_{t'} < \overline{Q} Q >$

A Chiral Fourth Generation

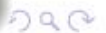
Motivation:

Why not ?

- 4G with $300 \text{ GeV} \lesssim m_4 \lesssim 600 \text{ GeV}$ not excluded by EWPT, if $\Delta m \leq M_W$
- Flavor bounds can be accommodated by suppressed mixings

Why ?

- Simplest (dumbest) extension of the standard model
- Fourth generation could be associated to EWSB. Large Yukawas naturally associated with strongly coupled sector.



Fourth SM Family Manifestations at CLIC

ÇİFTÇİ, ÇİFTÇİ, RECEPOĞLU, SULTANSOY

Table 1. Cross sections and event numbers per year for pair production of the fourth standard model family fermions with mass 320 GeV at CLIC ($\sqrt{s_{ee}} = 1$ TeV, $L_{ee} = 2.7 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$ and $L_{\gamma\gamma} = 10^{34} \text{cm}^{-2} \text{s}^{-1}$)

		$u_4 \bar{u}_4$	$d_4 \bar{d}_4$	$l_4 \bar{l}_4$	$\nu_4 \bar{\nu}_4$
e^+e^- option	σ (fb)	130	60	86	15
	N_{ev}/year	35000	16000	23000	4100
$\gamma\gamma$ option	σ (fb)	34	2	58	-
	N_{ev}/year	3400	200	5700	-

Table 2. Cross sections and event numbers per year for pair production of the fourth standard model family fermions with mass 640 GeV at CLIC ($\sqrt{s_{ee}} = 3$ TeV, $L_{ee} = 1 \times 10^{35} \text{cm}^{-2} \text{s}^{-1}$ and $L_{\gamma\gamma} = 3 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$)

		$u_4 \bar{u}_4$	$d_4 \bar{d}_4$	$l_4 \bar{l}_4$	$\nu_4 \bar{\nu}_4$
e^+e^- option	σ (fb)	16	8	10	2
	N_{ev}/year	16000	8000	10000	2000
$\gamma\gamma$ option	σ (fb)	27	2	46	-
	N_{ev}/year	8100	600	14000	-

$$u_4 \rightarrow b W^-$$

$$d_4 \rightarrow t W^+$$

$$l_4 \rightarrow \nu_\tau W^-$$

$$\nu_4 \rightarrow \tau^- W^+$$

Future

- Muon Collider Detector

start with 4th Concept Detector

Dual Readout Calorimeter

Dual Solenoid

Pixel/CluCou/SiT/TPC tracking

ILCroot software

More Collaborators

Benchmark physics processes

to do physics & background studies

- * MadGraph / Pythia 10,000 event samples
- * MARS Beam Background samples
- * ILCroot simulation + reconstruction

- 4th Family of Quarks & Leptons ?